# *The* TREND
## IN ENGINEERING

*at the University of Washington*

*In this issue:*


**GRADUATE STUDIES AND RESEARCH IN CIVIL ENGINEERING**

**THE GREEN-DUWAMISH RIVER: A RESOURCE STUDY**

**SUBGRADE FROST ACTION AND RELATED SOIL PROPERTIES**

**DOES VIBRATION AFFECT FRICTION IN A BOLTED JOINT?**



*October, 1957*

*Published quarterly*

*by*

THE ENGINEERING EXPERIMENT STATION

# WORDS AND REFLECTIONS

IN ITS ORIGIN, the word "engineer" reveals social implications as old as the human race. It stems from the same source as "ingenious," but by a more devious and sinister route. "Ingenious," literally, "showing inborn [quality or talent]," has continued to denote cleverness without malice. But long ago *ingenium,* the product of cleverness, came in Latin to be specifically attached to the fearsome contrivances of warfare, such as those invented by Archimedes and employed by the Syracusans against the Romans, and the battering rams used by the Romans against the Carthaginians. Hence the early "engine" was one designed for miltary use. The operator first became the *ingeniatorem* (late Latin), then the "ingeniator" (English, 12th century); later, he also became "one who designs and constructs military works" (1324).* The Romance languages continued with the basic Latin spelling, but English in the 14th century was beginning to use "engine," defined as "a machine used in warfare" (1300), and "a plot" (1400). In the King James version of the Bible (1611) the word appears twice; "battering engines" (Ezek. 26:9), and "engines, invented by skilfull men ... wherewith to shoot arrows and great stones" (II Chr. 26:15).

In the 16th century, the suffix, "-eer," which had become familar in military words of Romanic origin, was added. The earliest examples of its use included such phrases as "That great engineer, Satan" (1635), and "the devil's engineers" (1611).

In Swift's declaration: "The engineers of this bill thought they had obtained a great advantage against me" (1702), the overtones of hostility are clear. Today, the verb, "to engineer," retains this connotation, although it may be used quite inoffensively.

These words, although perhaps they strike closest home, are only members of a larger group.

The Latin word, *machina,* while used in general for mechanical devices, was also applied to engines of war. The English "machinations" and "machinator" have always been used in the sense of plotting and intrigue, implying, often, the intent or approval of evil forces. "Devise," "contrive," and even their more innocuous synonym, "invent," may convey the same idea. The only appearance of "invention" in the Bible is: "God hath made man upright; but they {women} have sought out many inventions" (Eccl. 7:29), which, if not quite clear in meaning, is unmistakable in intent!

In perspective, these associations wth cleverness may have a very old history. In primitive times, the "wise man," or shaman, of the tribe found it profitable to make use of his people's superstitious fears. He interpreted natural phenomena and often produced apparently supernatural prodigies to suit his own purposes. (Of course he was subject to two dangers: first, what people feared, they might hate, and second, he might be ousted by a still "wiser" man.)

As a consequence of this deep-seated fear of the new, the strange, and the inexplicable, *a man who knew too much,* who was *too inventive,* became suspect—he might be an enemy. History shows a long list of men who were martyrs to their cleverness.

Even the extensive Roman program of benevolent public works associated the engineer with military objectives, often unjustifiably, since the military organization was clearly the only division of the government that could possibly have done the job. Not until the formation of the Corps des Ponts et Chaussées in 1716, was an engineering group set entirely apart from a military corps.

John Smeaton, several decades later, was the first to refer to himself as a "civil" engineer. Thomas Telford, in the 1828 charter of the Institution of Civil Engineers, defined civil engineering as "the art of directing the great sources of power in nature for the use and convenience of man." The cleavage was complete.

Civil engineering, the progenitor of all other branches of engineering, has gradually relinquished to its offspring various specialized areas, but has held fast the ancient realm of "public works." Buildings, bridges, harbors, roads, safe and adequate water supplies—there are the professional interests of modern civil engineers. By their "ingenuity" they make for us a safer, a more convenient, and a more beautiful world in which to live.

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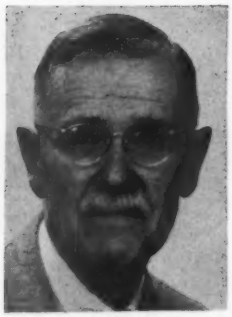
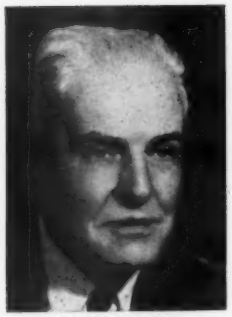
* The examples with dates used here and following are from the Oxford English Dictionary.



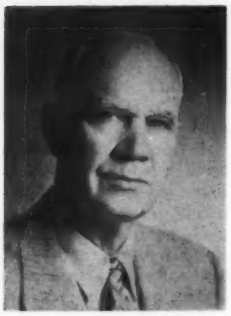
Almon H. Fuller
*1898-1917*

Charles W. Harris
*1917-1918*

Charles C. More
*1918-1927*



Alfred L. Miller
*1927-1929*



Richard G. Tyler
*1929-1937*

Robert B. Van Horn
*1937-*

## *Some Notes on . . .*
# Civil Engineering in the University of Washington

THE FIRST COURSE IN ENGINEERING offered by the University of Washington appeared in the catalogue for 1894-95 under the title, "Civil Engineering," and was taught by the instructor in Miltary Scence. Although courses in Electrical and Mining Engineering were announced for 1895-96, they did not materialize until 1898-99.

However, 1896-97 saw an ambitious step approved, the setup of the so-called "Stanford Plan." A College of Engineering was created (on paper, at least) to include three five-year courses leading to degrees in Civil, Electrical, and Mining Engineering. At the same time the Colleges of Mines and Mining and of Medicine and Surgery were outlined.

The engineering curriculum included as required subjects at least one year of foreign language (in addition to the general admission requirement of at least one year), Astronomy, Physics, Chemistry, and Political Science.

The catalogue for 1897-98 listed an imposing number of engineering courses, with blanks left for names of faculty members to handle them. Nevertheless, the pattern had been established, and the appointment of Almon H. Fuller in August, 1898, marked the actual beginning of engineering in the University of Washington.

Professor Fuller's responsibilities might well have daunted a less dynamic and gifted man. He was Dean of both the College of Engineering and that of Mines, Professor of both Civil and Mechanical Engineering, and sole member of the engineering staff. In addition, he was listed in the College of Liberal Arts, where he taught a course in Mechanics. That year there were 18 registrants in engineering courses; the next year, 40.

During Professor Fuller's 18 years at the University, he was gradually relieved of administrative and teaching duties outside of the College of Engineering and the Department of Civil Engineering, of which he remained Dean and Head, respectively. When he left the University to return to his alma mater, and, later, to head the Iowa State College department, his engineering teaching staff had grown to 18 members and the departmental faculty to ten.

The engineering course was reduced to four years in 1901-02. The first B.S. degree in Civil Engineering was awarded to two men in 1901. The number rose to 17 in 1915, but the impact of World War I reduced it in 1917 to nine. Fifty men were registered for Civil Engineering in 1917, including one from Moscow, Russia, and one from the Philippine Islands.

Following Professor Fuller, Charles C. More was appointed head of the Civil Engineering Department, but during 1917-18 he was on "war leave" to teach structures at West Point, and Charles W. Harris was appointed acting head. Professor More returned in 1918 and remained head until 1927 when, at his request, he was relieved of administrative duties, although he continued to teach until he retired in 1947. He has been called "the teacher extraordinary" not only because of his highly successful methods (he orginated the "problem method") but by the impact of his character and his supreme interest in his students' personal lives.

Both Professor Harris and Professor More were honored by giving their names to University buildings: the

*(Continued on page 32)*

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*at the University of Washington*

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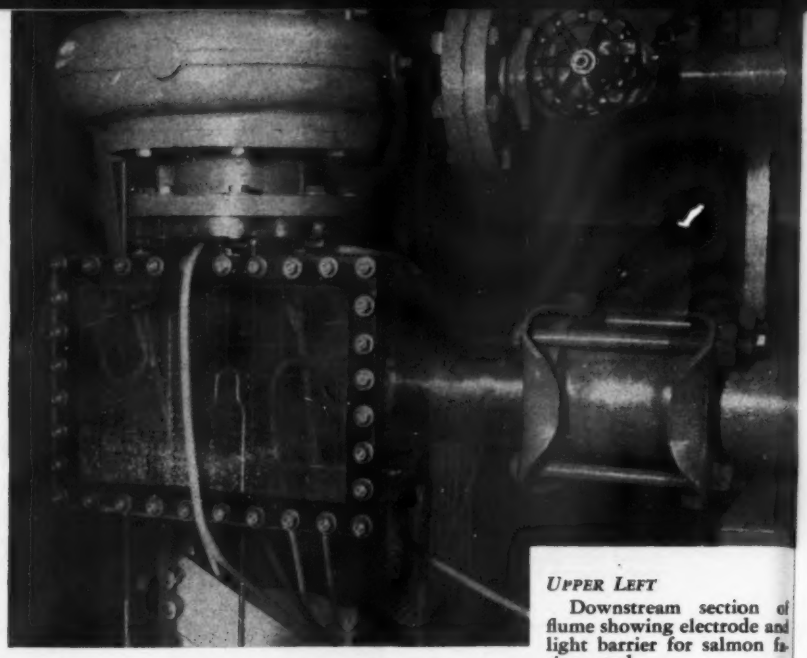
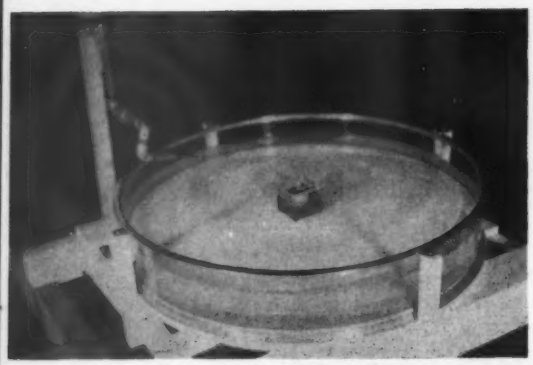
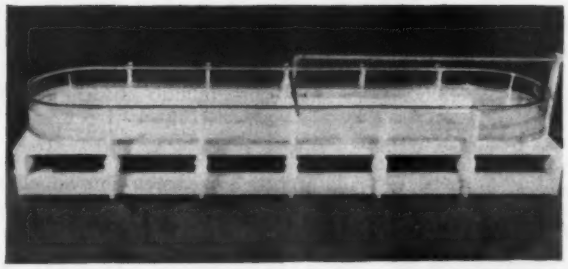


*Upper Left*

Downstream section of flume showing electrode and light barrier for salmon fatigue study.





*Upper Right*

Model of pump-section manifold for unwatering new type of dry dock to accommodate atomic submarines.

*Center*

Models for three types of fish-rearing ponds designed for hydraulic study.

*Courtesy,* U.S. Fish & Wildlife Service.

*Lower Left*

Model of Tolt River Reservoir Spillway.

*Lower Right*

View of flume and head-box on floating barge with pump in operation. *Salmon Fatigue Study, McNary Dam.*

# Graduate Studies and Research in Civil Engineering

## 1955-1957

DURING THE PERIOD 1955-57, 27 degrees of Master of Science in Civil Engineering were granted by the University of Washington. Graduate studies leading to the degree of Doctor of Philosophy in Civil Engineering were authorized in March, 1954.

Research programs of the Department of Civil Engineering are set up in five general fields: hydraulic engineering and fluid mechanics, sanitary engineering, soil mechanics, structural engineering, and transportation (highway) engineering.

### HYDRAULIC ENGINEERING

#### Extended Use of the Laboratory

The facilities of the Charles W. Harris Laboratory are often used for problems confronting the State Department of Fisheries. Members of the University staff frequently work directly on these projects. Some recent major studies in this group were the following:

1) Hydraulics of an artificial spawning channel.
2) Terminal velocity in air of fingerling salmon.
3) Effect of turbulence and rapid pressure reduction on fingerling salmon.
4) Hydraulics of a lower-type guidance for downstream migrants.

#### Sponsored Projects

PROJECT: To investigate the pressure field induced on a floating bridge by the passage of a large vessel.

SPONSOR: Washington Toll Bridge Authority.

Conducted by E. P. RICHEY, Associate Professor of Civil Engineering.

A theoretical analysis was made of the pressures that would develop on the open faces of a floating bridge due to the passage of a large vessel moving at a moderate speed. A related study was made of the hydraulic forces to be overcome during the opening cycle of the floating spans.

PROJECT: The Skimmer: A Part of the Downstream Migrant System, Mayfield Fish Facilities.*

SPONSOR: City of Tacoma, Department of Public Utilities, Light Division.

Conducted by E. P. RICHEY, Associate Professor of Civil Engineering.

A study was made of a 1:3 model of the hydraulic performance of a device designed as part of the downstream migrant system for the Cowlitz Dam at present under construction. The purpose of the device was to reduce the initial quantity of water needed for attracting fish to a level deemed adequate for subsequent transportation of the fish.

PROJECT: The Ladder and Powerhouse Collection Channel: A Part of the Upstream Migrant System, Mayfield Fish Facilities.†

SPONSOR: City of Tacoma, Department of Public Utilities, Light Division.

Conducted by E. P. RICHEY and H. H. CHENOWETH, Associate Professors of Civil Engineering.

The sponsor's design and model of the collection system for upstream migrants was tested through a wide range of operating conditions. Features requiring special attention were the methods of supplying auxiliary water to the system and various types of weirs and baffles.

PROJECT: (1) Spillway and Energy Dissipation System for the Tolt Reservoir Dam.
(2) Energy Dissipation Manifold for the Tolt River Pipeline (project just beginning).

SPONSOR: City of Seattle, Board of Public Works.

Conducted by E. P. RICHEY and H. S. STRAUSSER, Associate Professors of Civil Engineering.

1) The hydraulic performance of the different design arrangements for the proposed Tolt River Reservoir Dam was investigated on a model scale. Features of particular interest were the flow conditions at the entrance to the spillway and the diversion of the jet from the spillway back into the natural river channel.

PROJECT: Salmon Fatigue Study: An experiment to determine the swimming ability of upstream migrant sockeye salmon at various locations along the Columbia River.

SPONSOR: U.S. Army Corps of Engineers.

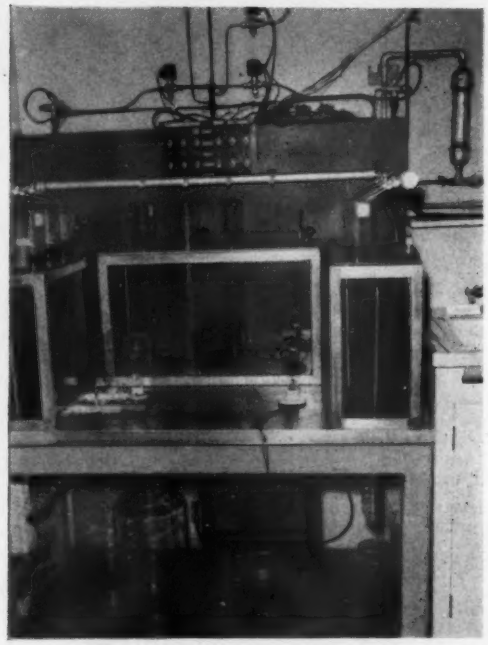
Conducted by A. C. DELACY, Associate Professor of Fisheries, Director, and J. C. KENT, Assistant Professor of Civil Engineering.

This project was part of an over-all program to determine means of safely passing both upstream and downstream migrant salmon by dams. Professor Kent designed and supervised construction of the hydraulic equipment.

In order that the experimental findings might be directly applicable, portable equipment was designed to be used at particular field locations on the Columbia River. The equipment consisted of a head box and a flume 25 ft in length mounted on a 45-ft

* See *The Trend in Engineering*, Jan., 1957.

† *Ibid.*, April, 1957.



*Clockwise from upper left:* (1) Algae culturing tank and gravity separator. (2) Field sampling equipment below Grand Coulee Dam. (3) Aerobic culturing facility. (4) Portable dredge water-treatment plant in Boise, Idaho. Units are being covered and insulated for winter operation. (5) One of the 14 x 50 x 10-ft water clarification units, Bear Valley, Idaho.

barge. The flow was supplied by a propeller pump with a 6500-gpm capacity. The velocity was regulated by the head box and the slope of the flume. The fish were induced to swim until exhausted by means of a barrier consisting of a weak electrical field combined with a powerful light. After the measurements of the salmon's swimming ability had been taken, the salmon were tagged and released to continue their upstream migration. Over 1000 swimming performance tests were completed during July and August, 1957. Samples of the sockeye run at McNary, Rock Island and Tumwater Dams were tested.

PROJECT: Investigation for Cavitation in Pump Suction Chest for Floating Dry Dock.

SPONSOR: W. C. Nickum & Sons, Architects and Engineers, Seattle.

Conducted by H. K. MORITZ, Professor of Hydraulics, and W. M. MILLER, Assistant Professor of Civil Engineering.

Pumping requirements for a newly designed floating drydock resulted in a somewhat unique flow distribution scheme demanding connection of three 24-inch pipes from different sources to the common suction of a centrifugal pump. To simplify construction, a plan was developed wherein all pipes terminated in a common chamber termed the "suction chest." The chest is connected directly below the vertical axis pump.

Designers became concerned over the complexity of flow patterns within the chest, and, recognizing no rational solution, requested a model study. Purpose of the investigation was three-fold:

1) to detect possible cavitation within the chest,
2) to investigate velocity distribution at point of connection to the pump,
3) to provide geometry modification necessary for elimination of any difficulty encountered with respect to the first two purposes.

A model with scale ratio of 1:6 was constructed of plexiglass, installed and tested in the Hydraulics Laboratory. Point pressures within the chest were observed and converted to prototype scale for comparison with pressures necessary to produce cavitation. Pitot traverses were made across the model throat. The transparent structure provided opportunity for visual observation, and test results indicated no disturbances sufficient to justify modification of the original design.

PROJECT: Evaluation of Three Types of Fish-Rearing Ponds

SPONSOR: Fish and Wildlife Service, U.S. Department of the Interior.

Conducted by R. E. BURROWS, Fishery Research Biologist, and H. H. CHENOWETH, Associate Professor of Civil Engineering.

Study of hydraulic, biological, and physical characteristics of three types of fish-rearing ponds was undertaken with the ultimate objective of either improving present types or developing new designs. Models were constructed of the three prototypes to determine hydraulic similitude. Flow patterns in models and prototypes were observed by the use of floats and dyes.

The model studies indicated that hydraulic characteristics of fish-rearing ponds may be studied satisfactorily in 1:10 scale models, with allowance for the influence of viscosity in the prototypes.

All three types of ponds studied have serious hydraulic defects, requiring major changes for correction. Criteria for development of improved fish-rearing ponds must be determined by further study of faults in existing ponds.

PROJECT: Use of Models to Facilitate the Design of Hydraulic Structures.

SPONSOR: Engineering Experiment Station (No. 197)

Supervisor: H. K. MORITZ, Professor of Hydraulics.
Graduate Assistants: L. Miao (M.S. thesis), T. K. Chu (continuing).

## SANITARY ENGINEERING

### Sponsored Projects

PROJECT: Water Quality Studies in the Columbia River Basin.

SPONSOR: U.S. Fish and Wildlife Service.

Conducted by R. O. SYLVESTER, Professor of Sanitary Engineering.

A study was made of the past, present, and predicted future water quality in the river basin and the effect that multi-purpose water usage has had on the water quality. Published as a Special Scientific Report of the U.S. Fish and Wildlife Service.

PROJECT: Biochemical Oxygen Demand of Magnesium Oxide Base Sulfite Waste Liquor in Sea Water.

SPONSORS: Alaska Lumber and Pulp Co. and Alaska Water Pollution Control Board.

Conducted by R. O. SYLVESTER, Professor of Sanitary Engineering.

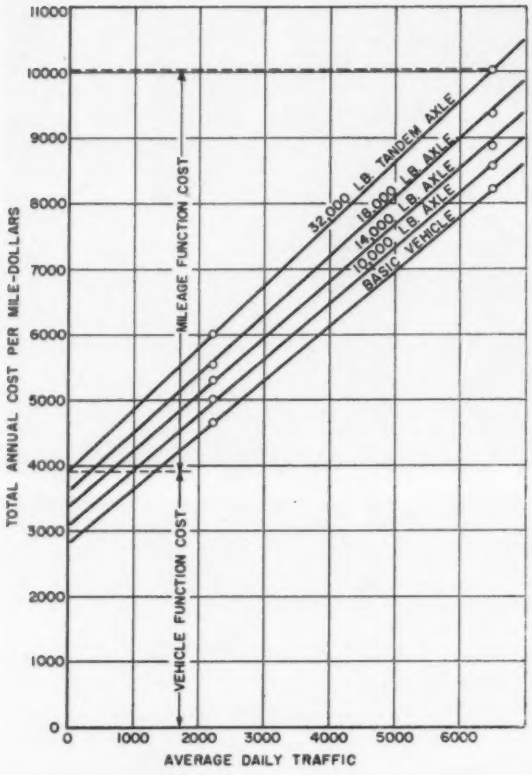
This laboratory study was in reference to a new pulp mill design for Sitka, Alaska.

PROJECT: Water Quality and Biological Studies in the Wenatchee and Middle Columbia Basin.

SPONSORS: The Chelan and Grant County Public Utility Districts, through the U.S. Fish and Wildlife Service.

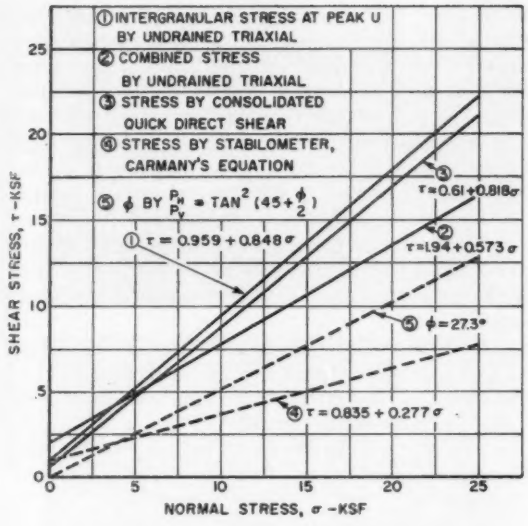
Conducted by R. O. SYLVESTER, Professor of Sanitary Engineering.

This water quality and biological study related to the construction of the Wenatchee, Rocky Reach,



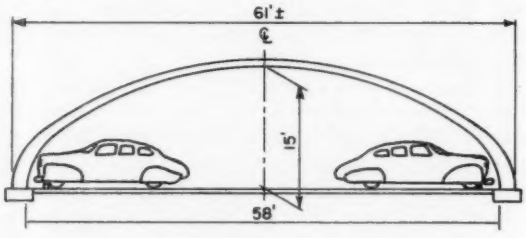

EFFECT OF FREQUENCY AND MAGNITUDE OF WHEEL LOADS ON ANNUAL COST OF RURAL HIGHWAYS

*Highway Cost Allocation Study.*


① INTERGRANULAR STRESS AT PEAK U BY UNDRAINED TRIAXIAL
② COMBINED STRESS BY UNDRAINED TRIAXIAL
③ STRESS BY CONSOLIDATED QUICK DIRECT SHEAR
④ STRESS BY STABILOMETER, CARMANY'S EQUATION
⑤ φ BY Ph/Pv = TAN² (45+φ/2)
τ = 0.959 + 0.848σ
τ=0.61+0.818σ
τ=1.94+0.573σ
⑤ φ=27.3°
τ = 0.835 + 0.277σ
SHEAR STRESS, τ - KSF
NORMAL STRESS, σ - KSF

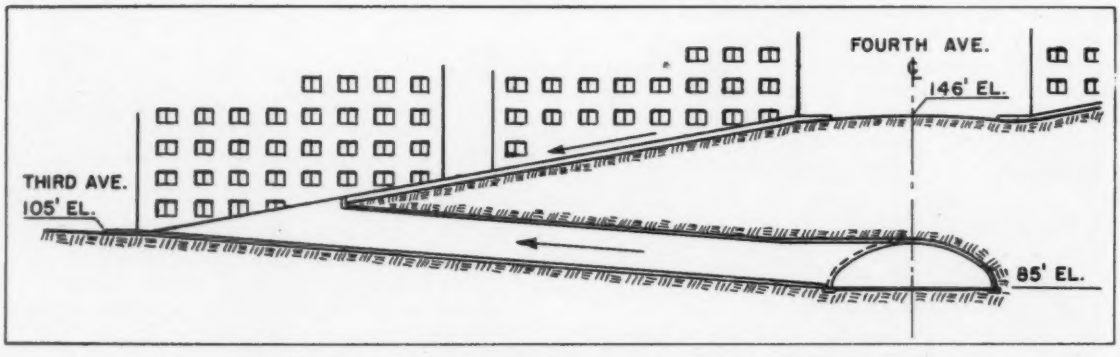
STRENGTH RELATIONSHIP FOR A PLASTIC SOIL OBTAINED BY VARIOUS METHODS OF SHEAR TESTING

Reported in *AAPT Proceedings*, 1956.




SECTION OF TUNNEL OF DOWNTOWN CIVIL DEFENSE SHELTER SHOWING PERPENDICULAR PARKING ON EACH SIDE

*Washington Survival Plan Studies.*




SUGGESTED USE OF DOWNTOWN CIVIL DEFENSE SHELTERS FOR UNDERSTREET PARKING

*Washington Survival Plan Studies.*

Wanapum and Priest Rapids dams. Report to be published.

PROJECT: Solids Removal from Highly Turbid Dredge Mining Waste Waters.

SPONSOR: Porter Bros. Corp., Boise, Idaho.

Conducted by R. O. SYLVESTER, Professor of Sanitary Engineering.

This was a laboratory study using synthetic polymers. Portable water treatment units were designed.

PROJECT: A Study of the Mechanism and Kinetics of the Biochemical Oxidation of Alkyl Aryl Sulfonates.

SPONSOR: Engineering Experiment Station (No. 201) Jan., 1956 to Oct., 1956.

Supervisor: R. H. BOGAN, Associate Professor of Civil Engineering.

Graduate Assistant: G. B. White (M.S. thesis).

The alkyl aryl sulfonate class of organic compounds was studied under laboratory conditions to ascertain their behavior during waste treatment and disposal. The chemical structure and configuration of the so-called alkyl portion of the molecule was found to exercise a limiting or controlling effect on the biological destruction of such substances.

Last year an estimated 1 billion pounds of this class of organic compound reached the nation's surface waters. Less than 10 years ago fewer than 3 million pounds were produced. Serious water pollution problems have been reported due to the presence of as little as one to two milligrams per liter of alkyl aryl sulfonates. Conventional waste treatment and disposal practices in some areas have not been able to cope with wastes containing these substances.

A number of alkyl aryl sulfonates were synthesized and studied in the laboratory. Special activated sludge cultures were developed on these substances. Information was obtained concerning the susceptibility of these compounds to biological treatment. Information also was established concerning the relationship of chemical structure to both the rate and the extent of biochemical oxidation.

PROJECT: Development of a Tertiary Algal Sewage Treatment Process.

SPONSOR: Engineering Experiment Station (No. 206).

Supervisor: R. H. BOGAN, Associate Professor of Civil Engineering.

Graduate Assistant: O. Albertson (continuing).

Research is being carried out on the use of special algae cultures or a means of removing nutrients from sewage-treatment plant effluents. Special culture apparatus and laboratory-scale treatment units have been constructed. Useful species, their growth rates and performance characteristics, are being studied.

Serious water quality-control problems have been encountered in recent years from prolific growths of algae in waters receiving nutrient-rich wastes. Sewage and industrial waste treatment as currently practiced does not remove significant amounts of the potentially troublesome nutrients normally present. In many inland areas future beneficial development of the natural water resources is threatened.

**Unsponsored Projects**

PROJECT: A Study of Present and Future Pollution Effects in the Green-Duwamish River.

Supervisor: R. O. SYLVESTER, Professor of Sanitary Engineering.

Graduate Student: R. W. Okey (M.S. thesis).*

PROJECT: Water Quality Studies in the Wenatchee River Basin.

Supervisor: R. O. SYLVESTER, Professor of Sanitary Engineering.

Graduate Student: R. W. Seabloom, M.S. thesis to be published by U.S. Fish and Wildlife Service.

**Program for Nuclear Engineering Education**

During the past two years the Sanitary Engineering faculty has been offering a graduate-level course on Control of Radioactive Wastes, to students in nuclear engineering and to A.E.C. Health Physics Fellows. This course deals with the environmental and sanitary engineering aspects of the nuclear energy industry and is concerned with such problems as the treatment and disposal of radioactive wastes, reactor site location and hazards studies, decontamination of water supplies and the measurement of stream and atmospheric pollutions by radioactive materials.

A radioactive "hot lab" is being established in the Sanitary Engineering Laboratory for both teaching and research. Equipment for class use was made available through an Atomic Energy Commission grant of $9215 to develop teaching facilities.

## SOIL MECHANICS TRANSPORTATION ENGINEERING

**Projects Sponsored by State and Federal Agencies**

During the biennium, October, 1955, to October, 1957, research in the field of highway finance, economics and planning, under the direction of Professor Robert G. Hennes, was maintained at the high level of activity which had been attained during the preceding four years. Most of this effort transcended departmental lines, and while highway projects were administered under the Department of Civil Engineering, the staff included many faculty and graduate students from the College of Arts and Sciences, and from the College of Business Administration. An inquiry into the equitable allocation of road and street costs, begun in 1953, was completed in June, 1956, and reported to the Joint Fact-Finding Committee on Highways, Streets and Bridges of the

* See page 13.

*ABOVE*

*Left*

Measuring shrinkage of concrete specimen in study of unsymmetrically reinforced beams.

*Right*

Bolted joint specimen in the 2,400,000-lb testing machine for study of the effect of the one-turn-of-the-bolt method of tightening the bolts. The operator is adjusting the elongation gage.

*BELOW*

Steel beam specimen in a cooling box to observe formation of plastic hinges at low temperature.

Washington Legislature. This project was sponsored by the Washington State Council for Highway Research. The final report amounted to more than 1500 pages in nine volumes, in addition to a pamphlet reporting a summary of the findings. Important contributions to the total effort included Professor Martin Ekse's development of an incremental cost solution; Professor Earl Hald's discussion of credit financing; Professor Joseph McGuire's work on the statistical bases for weight-distance taxation in the State of Washington; Professor William Garrison's analysis of the effects of road improvement on rural property values; Professor Bayard Wheeler's inquiry into the effect of freeway access upon suburban real property values, and Professor Stanley Brewer's scrutiny of the status of commercial motor carriers as highway users in Washington. The highway cost allocation study in its various aspects has provided material for a number of scientific papers, has aroused national interest, and has become a significant factor in the formation of highway policy at both national and state levels.

During the 1957-59 biennium, research for the Legislature's Interim Highway Committee is continuing on an equal scale but in a more diversified pattern. Under the general heading of "Highway Economic Studies" a large staff is investigating (1) the desirability of motor vehicle licensing, (2) existing and proposed exemptions from motor vehicle taxation, (3) the highway tax structure, (4) the impact of monthly licensing of motor vehicles, (5) the future development and financing of urban freeways, (6) the value of access and severance, and the economic effect of highway improvements (or bypasses) on communities. In addition to graduate students, the research staff includes Professors Hennes, Ekse, Horwood, Meese, and Sawhill of Civil Engineering; Professors Garrison and Marts of Geography; Professors Archer, Goldberg, Lambright, Little, and Seyfried of Business Administration; and Research Associates Myers and Pollock of Economics.

Similar in their interdisciplinary character, but even broader in scope were the Washington State Survival Plan Studies conducted during the summer of 1956 and administered under Civil Engineering. This comprehensive study for the Washington State Department of Civil Defense and the Federal Civil Defense Administration dealt with the possible effects of an atomic attack on the State, and was primarily concerned with data and planning to cope with this potential situation. In addition to a general discussion of the Civil Defense problem and its implications, the report provides a large compendium of current data on population, public information, transportation, protection against weapon effects, the role of government, current civil defense planning, and estimates of mass care requirements in the event of disaster. The staff included Professors Hennes, Chittenden, Clanton, Ekse, and Tyler of Civil Engineering; Bone, Gore, Harbold, Laird and Shipman of Political Science; Brier of Journalism; Garabedian, Graalfs, Hays, and McCarthy of Sociology; Garrison and Marts of Geography.

The Highway Cost Allocation Project, the Highway Economic Studies, and the Washington State Survival Plan Studies were conducted under the general direction of Professor R. G. Hennes.

**Other Sponsored Projects**

PROJECT: Highway Test Track.
SPONSORS: Asphalt Institute and Asphalt Paving Association of Washington.
Conducted by M. EKSE, Associate Professor of Civil Engineering.
Graduate Student: L. La Cross (M.S. thesis).*
Early findings reported at the 1957 meeting of AAPT in Atlanta, Ga. (Continuing)

PROJECT: Cooperative Triaxial Test Investigation.
SPONSOR: Engineering Experiment Station (149)
Supervisor: R. G. HENNES, Professor of Civil Engineering.
Research Assistants: W. D. Finn (M.S. thesis) and B. Strom (M.S. thesis).†

PROJECT: Drainage of Cohesionless Soils.
SPONSOR: Engineering Experiment Station (205)
Supervisor: R. G. HENNES, Professor of Civil Engineering.
Research Assistant: J. Brulois (continuing).

PROJECT: Influence on Confirming Pressure in Triaxial Testing.
SPONSOR: Engineering Experiment Station (221)
Supervisor: R. G. HENNES, Professor of Civil Engineering.
Research Assistant: R. Long (continuing).

Work on these three projects has been largely correlated with the cooperative research programs of the Triaxial Institute for Structural Pavement Design, of which Professor Hennes is the current chairman.

PROJECT: Plan of Harbor Models. (Completed)
SPONSOR: Engineering Experiment Station (226)
Supervisor: R. G. HENNES, Professor of Civil Engineering.
Research Assistant: K. D. Hoyt (M.S. thesis).

**STRUCTURAL ENGINEERING**

**Sponsored Projects**

PROJECT: Bolted Joint Research.
SPONSOR: The Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation and the Washington State Council for Highway Research.

*(Continued on page 32)*

* See *The Trend in Engineering*, April, 1956.
† *Ibid.*, July, 1957.

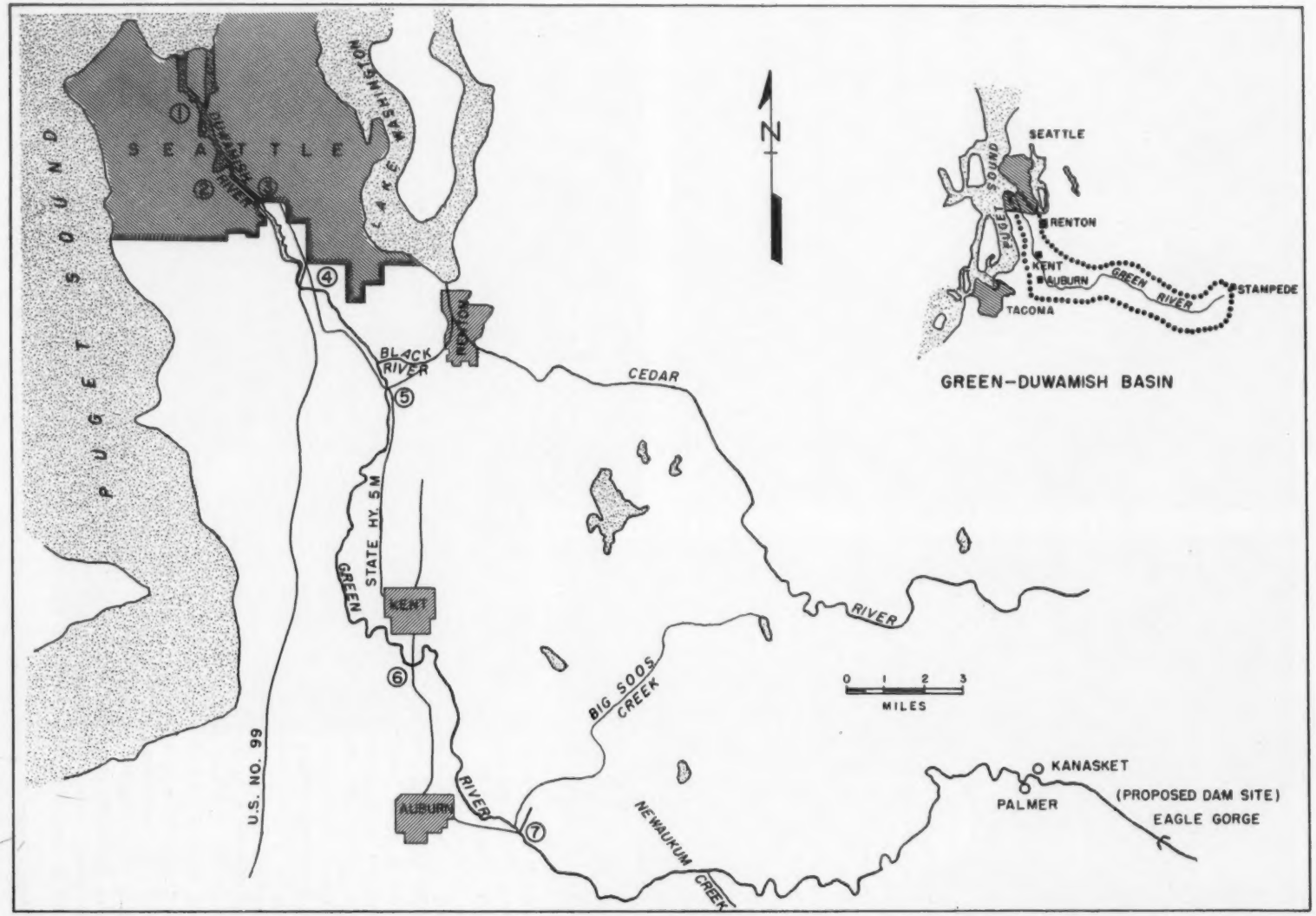



FIG. 1. WESTERLY PORTION OF THE GREEN-DUWAMISH RIVER BASIN SHOWING SAMPLING STATIONS

# THE GREEN-DUWAMISH RIVER: A RESOURCE STUDY*

ROBERT W. OKEY†
*Engineer and Graduate Student*
*Department of Civil Engineering*

R. O. SYLVESTER
*Professor of Sanitary Engineering*

R. W. Okey

This report presents a condensation of the results of a water-pollution study of the Green-Duwamish River located in King County, Washington. Four of the significant pollution factors have been analyzed and certain basic conclusions drawn. Such a study was considered desirable for three reasons.

First, the stream is at some intermediate point of biochemical and physical degradation[1] and a study may aid in maintenance of this water resource.

Second, the industrial expansion aimed at the Duwamish Basin[2] will produce additional industrial wastes. It is important to know the ability of the river to assimilate these wastes, together with a natural increase in domestic wastes.

Third, a study of stream conditions under projected loadings will provide data on present and future sewage-disposal practices.

The Green-Duwamish River supports or lends itself to almost all the major water uses common to the area, with the exception of hydroelectric power generation. These uses follow.

1. Public and industrial water supply
2. Game fish propagation
3. Commercial fish propagation
4. Boating and commercial shipping
5. Swimming
6. Irrigation.
7. Waste disposal and assimilation

The measurable water-quality factors which affect the uses of the water resource are as follows:

1. Dissolved oxygen concentration
2. Water temperature
3. Hydrogen ion concentration (pH)
4. Chlorinity
5. Turbidity and resultant siltation
6. Bacterial contamination
7. Toxic elements or materials
8. Esthetic factors (oils, floating solids, etc.)

This study considers only the first four factors.

* A condensation of Mr. Okey's thesis submitted in partial fulfillment of requirements for the degree of M.S. in Civil Engineering, 1957.

† Now Project Engineer, Howard T. Harstad & Associates, Consulting Engineers, Seattle.

## The Study Area

R. O. Sylvester

The Green-Duwamish River rises in eastern King County at the crest of the Cascade Mountains. It flows westerly to Auburn where it changes direction and flows northwesterly to Puget Sound. At Black River Junction, near Tukwila, the Black River formerly joined the Green and the combined flow became the Duwamish River. The Black River was virtually eliminated as a drainage channel after construction of the ship canal and the lowering of Lake Washington. From Black River Junction northward, the river is known as the Duwamish for a distance of 12 miles, the last 7.5 miles of which have been improved for navigation. This dredged reach is known as the Duwamish Waterway. The total drainage basin area is 474 square miles.

The drainage area (Fig. 1) is divided into two distinct geographical areas: the mountainous forested area above Auburn and the agricultural and industrial area extending from Auburn to Puget Sound.

The one major diversion on the Green River is near Palmer, where the city of Tacoma diverts up to 100 cfs for public water supply. No regulation exists on the main river but there is minor regulation on Big Soos Creek, a tributary. There are substantially 100 additional minor diversions on the river for irrigation and domestic supply.

The Corps of Engineers is currently planning the construction of a flood-control dam near Eagle Gorge which will provide seasonal regulation on the main stem of the river. The total storage capacity of the dam will be 106,000 acre-feet with a summer conservation storage of 28,000 acre-feet. The proposed reservoir has sufficient storage to supply continuously at least 210 cfs, of which Tacoma may divert 100 cfs from March until September in the driest year on record, without interfering with its use for flood control. The reservoir will be empty on November 1. Some storage will be accrued in February, and from March 1 until June the reservoir will be operated for flood control and may

TABLE I

WATER QUALITY STANDARDS

| USE | D.O.* MIN. | MAX. TEMP. (° F) | pH RANGE | CHLORINITY (max. ppm) |
|---|---|---|---|---|
| Water Supply | | | | |
| Domestic | .... | .... | 8.0-10.6† | 250† |
| Industrial | .... | .... | .... | Depends on process |
| Salmanoid Fisheries | | | | |
| Propagation | 5.0 | 68‡ | | |
| Boating | .... | .... | .... | .... |
| Irrigation | .... | .... | 6.0-8.5 | 5000 |

* Dissolved oxygen.
† Reference 4.
‡ Reference 5.

acquire enough water to meet summer water demands. However, the storage plan as proposed by the Corps of Engineers would not obligate them to supply the requirements of any existing water rights other than to always release, during periods of low flow, at least the amount of natural flow into the reservoir.[8]

## The Problem

The preservation of the water resource for its legitimate uses is the ultimate philosophy of water-pollution control.

Table I presents quality criteria on the four water-quality factors studied in their relationship to the significant water uses (other than waste assimilation) that exist in the Green-Duwamish River System. This table indicates that the highest quality requirements are for domestic supply purposes and the propagation of the salmanoid fishes.

***Waste Disposal.*** Data on these water-quality indicators, dissolved oxygen, temperature, pH, and chlorinity, were collected by the city of Seattle, the Pollution Control Commission, and the writers, over three extended periods since 1948.

The city of Seattle, in its sanitary survey of the Duwamish River[7] established a number of sampling stations on the lower river below the Highway 99 Bridge. Data have been used here from six of these stations at the following locations:

1. Associated Oil Dock (near Elliott Bay)
2. General Contractors Dock (near Spokane Street)
3. Army Engineers Dock (above Spokane Street)
4. First Avenue South
5. Fourteenth Avenue South
6. Highway 99 Bridge (PSH #1)

The sampling period at these stations extended from November, 1948, to April, 1950, two to three times weekly. Each sample was analyzed for temperature, dissolved oxygen (D.O.), biochemical oxygen demand (B.O.D.), coliform organisms (MPN), salinity, and pH.

In 1955, the Washington Pollution Control Commission established the following stations at several points on the river below Auburn for a study of pollution factors:

1. Above Auburn (Maple Valley Bridge)
2. Above Kent (between Kent and Auburn)
3. Tukwila Bridge (Renton-Tukwila Bridge)
4. Highway 99 Bridge
5. Fourteenth Avenue South
6. First Avenue South
7. Spokane Street

The samples were collected about three times monthly and analyzed for chlorinity, dissolved oxygen, biochemical oxygen demand, temperature, pH, and coliform organisms.

The writers established sampling stations at the above points and collected samples twice a month during the warm weather low-flow period and once a month during the cold weather high-flow period. The primary purpose in collecting these samples was to determine if major changes had occurred since the earlier work.

## Present Source of Wastes

The Green-Duwamish River System receives large quantities of treated and untreated organic and inorganic wastes originating in municipalities and in industries. Auburn, Kent, King County Drainage District #4 (Skyway), the Val Vue Sewer District, and the city of Seattle discharge wastes to the river that are given varying degrees of treatment. Auburn, Kent, and Seattle treat varying quantities of industrial wastes which have been discharged to their respective sanitary sewer systems. Organic and inorganic industrial wastes are discharged directly to the river at various points, principally in the dredged estuary. In addition, the untreated sewage from approximately 45,000 persons is discharged through the city of Seattle sewer system to the dredged estuary, and the sewage of 2,000 persons from industries adjoining the river is discharged directly to the estuary. Table II is a summary of the domestic wastes entering the river between Auburn and the mouth.

Industries along the lower river, principally the dredged estuary, produce large quantities of inorganic chemical wastes, some of which are toxic. These wastes are made up, for the most part, of cyanides, chromates, pickling liquors, caustics, acids, greases, phenols, and pentachlorophenols. Some wastes receive complete treatment, or neutralization, and some are discharged untreated.

The coming era of increased industrialization and the expansion of the Duwamish Waterway will bring with it increased problems in industrial waste disposal. It is predicted that the bulk of the industrial development to come to the King County area will be centered in the Duwamish industrial area,[2] and that

**TABLE II**

**SEWAGE-TREATMENT PLANT AND RAW SEWAGE DISCHARGE B.O.D.* Discharged to River in Population Equivalent†**

| SOURCE | QUANTITY | POINT OF DISCHARGE |
|---|---|---|
| S.T.P. at Auburn | 5,690 | Auburn |
| S.T.P. at Kent | 5,200 | Kent |
| S.T.P. at Skyway | 2,000‡ | Tukwila |
| S.T.P. at Val Vue | 1,850‡ | Tukwila |
| S.T.P. at Seattle | 31,500‡ | Lower Estuary |
| Sanitary sewage direct from industries | 1,935 | Lower Estuary |
| From Seattle sewer outfalls (untreated) | 45,000 | Lower Estuary |

* Data for effluent biochemical oxygen demand were obtained from Ref. 1.
† Based on 1 P.E. = 0.17 lb/day, 5-day 20° C, B.O.D.
‡ Estimated by assuming 30% B.O.D. reduction.

the industries considered to have the best possibilities of development are the following:

1. Paper processing industries
2. Aluminum processing
3. Concrete products manufacturing
4. Ceramic products manufacturing
5. Gypsum products manufacturing
6. Iron and steel mill products
7. Iron and steel manufacturing
8. Garment production
9. Luggage production
10. Printed matter

Most of these industries produce wastes having a high oxygen demand. This will present a problem to state regulatory agencies regarding treatment criteria, since there is, at present, no surplus of dissolved oxygen during periods of low flow.

***Presentation of Data.*** Figures 2 and 3 present the dissolved oxygen data and the maximum chlorinity, minimum and maximum pH, and the maximum water temperature observed in 1956-57.

***Data Analysis.*** A study of the data gathered since 1955 indicates a present or approaching overload of the stream's capacity below Tukwila to assimilate wastes or alteration to flow that will affect its temperature. Critical water-quality factors are the low dissolved oxygen values and the high maximum temperature in this lower stretch of the river. Observations by fisheries and pollution authorities indicate a minimum level of 5.0 ppm of dissolved oxygen should be maintained for the propagation and promulgation of aquatic life, including the salmon. Certain pollution-control groups favor raising this figure to 6.0 ppm.[6]

Salt water intrudes as far as Renton Junction (Station 5, Fig. 1). Water salinity is a function of river flow and tidal movement. Its principal value in this study lies in its relationship to oxygen solubility. Values of pH ranged from 6.7 to 8.1. These are normal values for an estuarine area and indicate an absence of appreciable quantities of alkaline or acid wastes.

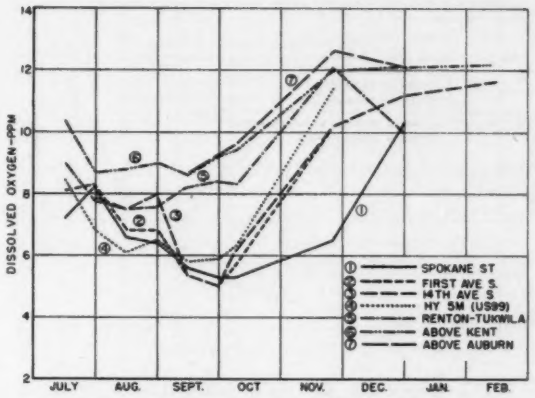



FIG. 2. PRESENTATION OF 1956-1957 DATA

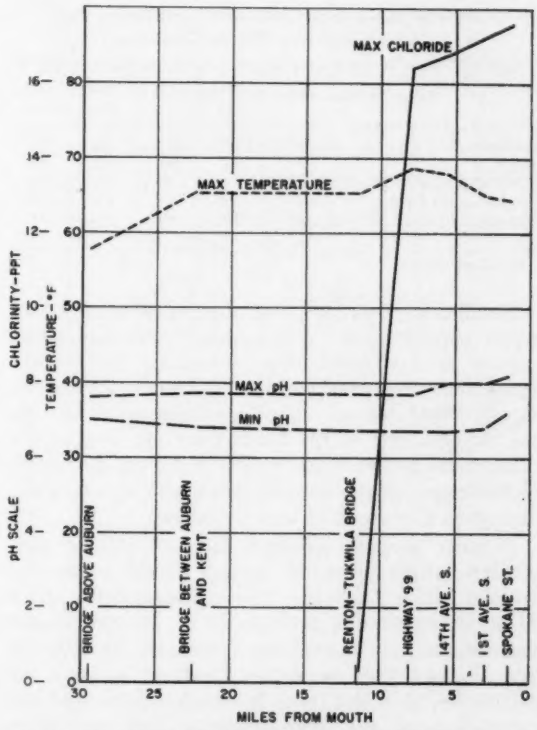



FIG. 3. CHLORIDE INTRUSION, MAXIMUM TEMPERATURES, AND EXTREME pH VALUES

Water temperatures above 65° to 68° F give rise to the virulent form of the myxobacteria *Chrondrococcus columnaris* which attacks game and rough fish, alike.[5] Sample catches in Eastern Washington streams have shown that almost all fish are attacked when the water temperature is above 68° F for any extended period. The disease is a disintegrative type and apparently 100 per cent fatal.

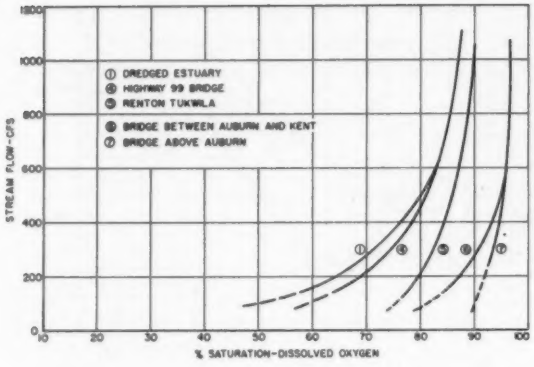



FIG. 4. PER CENT SATURATION-REGRESSION CURVES

TABLE III

MOST PROBABLE PER CENT SATURATION OF D.O.* UNDER PRESENT WASTE LOADING

| STATION | 100 CFS | 200 CFS | 300 CFS | 400 CFS |
|---|---|---|---|---|
| Auburn | 90 | 92 | 94 | 95 |
| Kent | 81 | 87 | 91 | 93 |
| Renton-Tukwila Bridge | 76 | 80 | 83 | 85 |
| Highway 99 Bridge | 59 | 69 | 74 | 78 |
| Dredged Portion of Estuary | 50 | 65 | 72 | 78 |

* Dissolved oxygen.

Insufficient data are available to predict future water temperatures. Water temperature rise above normal is associated with diversions and return flows, impoundments, and the addition to the stream of hot waste waters. The significant point is that the temperatures in the lower river are now in the dangerous bracket of 65° to 68° F during the period of movement of the downstream migrants, i.e., July, indicating an important area of concern.

A more positive approach can be made on predicting future dissolved oxygen levels under increased waste loadings. The conventional method of approach to this problem is to use the classic deoxygenation and reaeration equation of Streeter and Phelps. This technique, however, involves the calculation of travel times between stations and the calculation of the deoxygenation and reaeration constants. This method was not used because of the time required to obtain the constants and because of the error involved in these calculations for a tidal estuary.

The technique proposed by Churchill,[8] which relates oxygen sag to flow and measurable organic load at a given station, offers a more desirable way of predicting the sag in future dissolved oxygen levels.

To apply this technique (in this case within a true estuary), the per cent saturation of dissolved oxygen

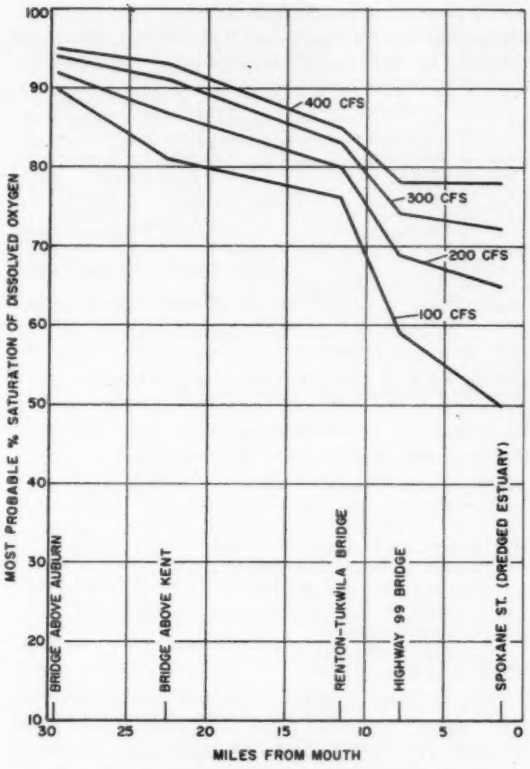



FIG. 5. PER CENT SATURATION-DISSOLVED OXYGEN SAG CURVES

was used to take into account the varying chlorinity and temperature which affect the dissolved oxygen saturation level. The analysis was made for the months of June, July, August, and September, when the temperature was in the range of 55° to 65° F.

The per cent saturation of dissolved oxygen was plotted against the flow for all the available data.* A curve showing the per cent saturation of dissolved oxygen regression was obtained for each station (Fig. 4). The most probable per cent saturation of dissolved oxygen could then be obtained for a flow of 100, 200, 300, and 400 cfs. (See Table III and Fig. 5.)

The total organic load and the point where it reached the river is summarized in Table IV.

From the loads summarized in Table IV and the most probable per cent saturation levels, a population-equivalent load unit/cfs and sag relationship can be derived for each station (Fig. 6). Sufficient information can be derived from the figure to predict the dissolved oxygen levels for varying organic loads at different points in the river.

* Recent research[9] indicates that the per cent oxygen saturation values used herein are about 4 per cent too low.

**TABLE IV**

**TOTAL APPLIED BIOCHEMICAL OXYGEN DEMAND***

| STATION | B.O.D. APPLIED (P.E.)† | B.O.D. SUMMATION (P.E.) |
|---|---|---|
| Vicinity of Auburn‡ | 5,690 | 5,690 |
| Vicinity of Kent | 5,200 | 10,890 |
| Renton-Tukwila Bridge | 3,750 (Domestic)<br>1,470 (Industrial) | 16,100 |
| Highway 5M Bridge<br>Highway 99 Bridge<br>Lower Estuary Total | 76,500 (Domestic)<br>2,150 (Industrial) | |
| (14th Avenue South<br>(1st Avenue South)<br>(Spokane Street) | | |
| Total Load Applied to River..... | | 94,750 |

* Reference 1.
† Population equivalent.
‡ No appreciable quantities of wastes are discharged above Auburn.

**TABLE V**

**DERIVED OXYGEN SAG DATA FOR 50,000 P.E.* LOAD UNITS DISCHAREGD NEAR RENTON-TUKWILA BRIDGE**

| STATION | FLOW | TOTAL LOAD | LOAD/ CFS | ESTIMATED PER CENT SATURATION DEPLETION (including background) | D.O.† (ppm) |
|---|---|---|---|---|---|
| Highway 99 Bridge | 100 | 50,000 | 500 | 52.5 | 4.7 |
| | 200 | | 250 | 42.0 | 5.7 |
| | 300 | | 167 | 37.5 | 6.3 |
| | 400 | | 125 | 32.5 | 6.7 |
| Dredged Estuary | 100 | 128,650 | 1,286 | 47.5 | 5.1 |
| | 200 | | 643 | 38.0 | 6.0 |
| | 300 | | 429 | 31.0 | 6.7 |
| | 400 | | 321 | 26.5 | 7.0 |

* Population equivalent. A population of 34,000 has been added to the present background population.
† Dissolved oxygen at mean summer temperatures and chlorinities. Values would be lower under maximum temperatures and chlorinities.

The following tables and figures present the synthetic dissolved oxygen sag data for

1) 50,000 P.E. load units applied at the Renton-Tukwila Bridge (Table V, Fig. 7),
2) 100,000 P.E. load units at the Renton-Tukwila Bridge (Table VI, Fig. 8),
3) 50,000 P.E. load units at the Renton-Tukwila Bridge and 50,000 P.E. load units in the dredged estuary (Table VII, Fig. 9).

## Summary and Conclusions

A study has been conducted to determine the degree of pollution resulting from changes in river flow and the discharge of sewage and industrial wastes to the river. The degree of pollution was measured by testing the river water for dissolved oxygen, temperature, pH, and chlorinity. The data from all available sources were collected and analyzed, along with data collected by the writers.

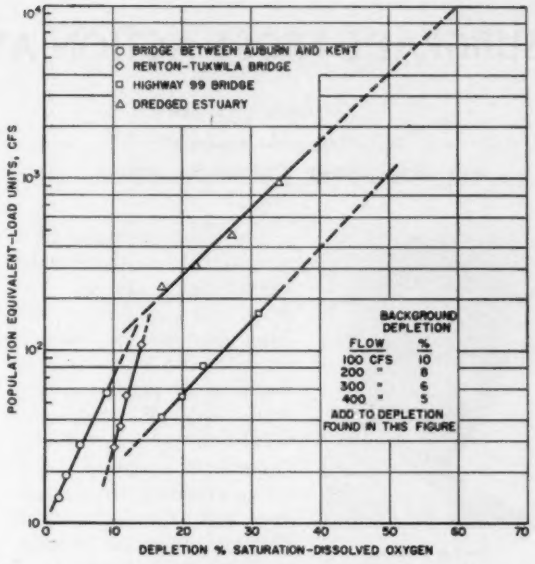



FIG. 6. POPULATION-EQUIVALENT LOAD UNITS/CFS VS. PER CENT SATURATION-DISSOLVED OXYGEN DEPLETION

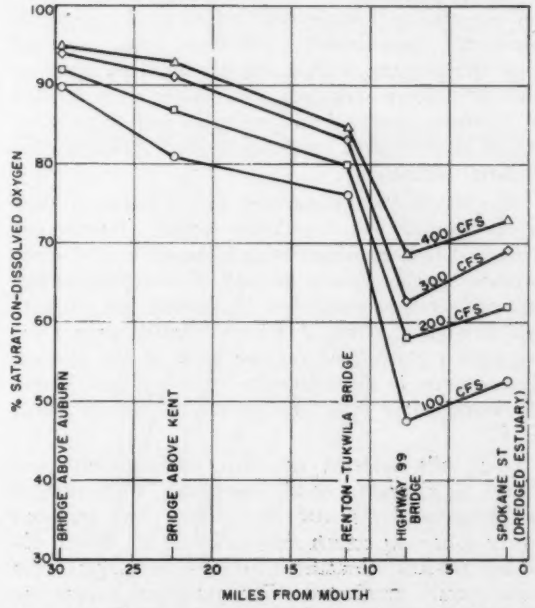



FIG. 7. SYNTHETIC SAG CURVES FOR 50,000 P.E. LOAD UNITS DISCHARGED NEAR RENTON-TUKWILA BRIDGE

A technique for the prediction of dissolved oxygen levels under various flow conditions and for various organic loadings has been developed by adapting an established method for use within the partially saline waters of the estuary.

*(Continued on page 30)*

# SUBGRADE FROST ACTION AND RELATED SOIL PROPERTIES*

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*Professor of Civil Engineering*

George Yamane

The phenomenon of frost action with its detrimental effects on roads and airfields is a complicated one. The elements of climate, the soil, the water in soil, the type of pavement, and traffic are all factors involved in causing different degrees of damages. Any action resulting from freezing and thawing which changes the water content, porosity, and structure of the soil will affect bearing capacity.

The present paper reports a study made to correlate certain soil properties such as sand equivalent, capillarity, permeability, and frost index number, with the amount of frost heave caused by freezing soils of different textures. Specimens were formed of carefully prepared soil samples, and these were frozen at controlled temperature in a specially constructed cabinet.

The test cabinet is insulated with 5 inches of glass wool covered with insulation paper. Refrigerant (Freon 12) is provided by a ¼-hp air-cooled compressor attached to the cabinet. Cooling inside the test cabinet is accomplished by passing the refrigerant through a 19-by-22-inch zinc-coated copper refrigeration plate fitted on two sides of the cabinet. Temperature in the cabinet is controlled by a Ranco thermoregulator with an accuracy of plus or minus 5° F.

The soils selected for this investigation consisted of river-run sand intermixed with various percentages of silt and clay. Sand was screened to the following screen sizes: No. 10-20, 20-40, 40-60 and 60-200. Gradations for various samples were thus readily duplicated. The gradation curves for Samples No. 1-8 and 10-16 are shown in Figs. 1 and 2, respectively. Samples No. 1-9 were sand intermixed with silt, and Samples No. 10-17 were blended with clay. Only Minus No. 10 sieve size material was used for this investigation because of the small size of the samples.

* Abstracted from Mr. Yamane's thesis, submitted in partial fulfillment for the degree of M.S. in Civil Engineering, 1955.

R. G. Hennes

Test specimens 5.6 inches long and 1.3 inches in diameter were compacted with the Harvard compaction tamper at 10 layers, twenty-five 40-lb tamps per layer. Three hundred grams of dry soil was prepared and compacted at 7 to 11 per cent water content, depending on the type of soil.

All specimens were tested in an open system and were saturated prior to freezing. Saturation was carried out in the cold room at a temperature of 40° F. Specimens were placed in a jar filled with distilled water with the water level approximately ¼ inch below the top of the sample, and were saturated for a minimum of 24 hours.

After saturation, the specimens were placed in the freezing cabinet. The pan was filled with distilled water cooled to 40° F and the compartment for the individual sample was filled with sand up to ⅛ inch below the water level. The water level was kept at a constant height by the vertical standpipe at approximately ¼ inch below the top of the pan. After the samples had been placed in their respective compartments, the space between the samples and cover was plugged with cheese cloth to prevent the insulation material from seeping into the pan. (The samples were insulated with expanded mica to the top of the specimens.) After the insulation around the samples had been compacted, heave measuring sticks were placed in position, as shown in Fig. 3, and initial readings were taken. No surcharge was used.

The freezing test was performed by closing the lid and lowering the temperature in the cabinet. Duration for one setting on the thermoregulator was two days. Temperature was dropped every consecutive two days. Twenty-four hours after a setting on the Ranco thermoregulator, temperature readings were taken through the thermopane window from the thermometer placed inside the cabinet. Figure 4 shows the temperature variation for one cycle (period of cut-in to cut-in of compressor) for the different settings. The average of maximum and

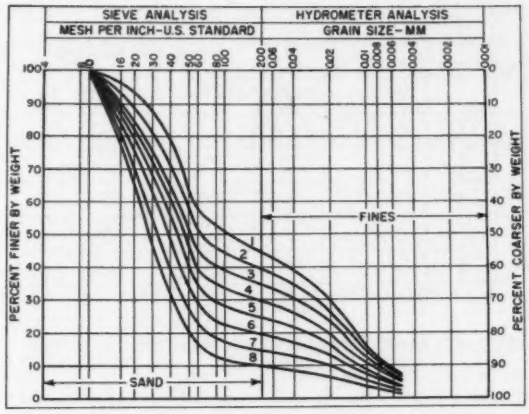


FIG. 1. GRADATION CURVES FOR SAMPLES 1 TO 8

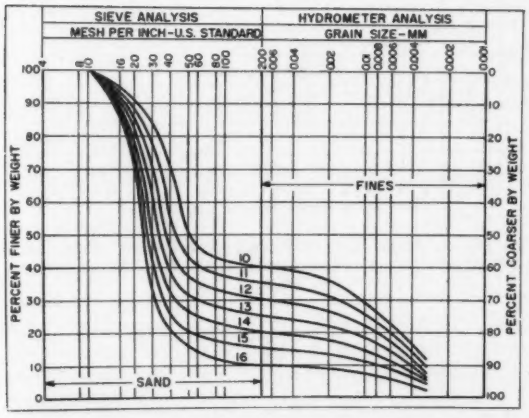


FIG. 2. GRADATION CURVES FOR SAMPLES 10 TO 16

FIG. 3. SIMULATED FREEZING TEST IN OPERATION SHOWING MEASURING STICKS

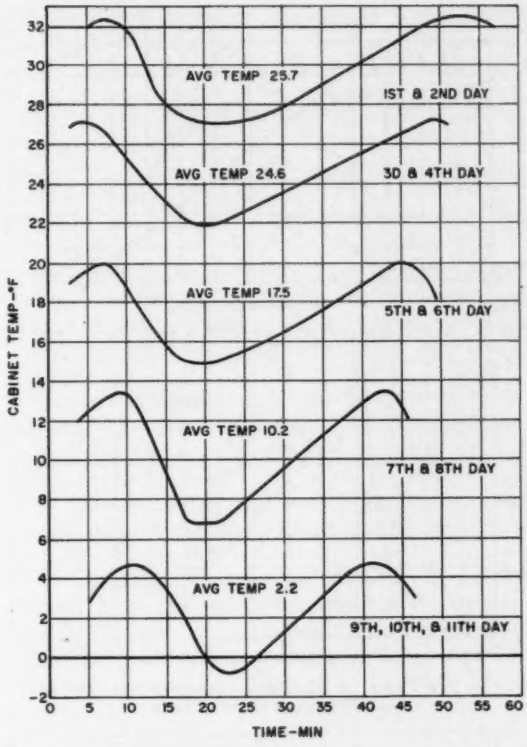


FIG. 4. TEMPERATURE VARIATION OF FREEZING CABINET

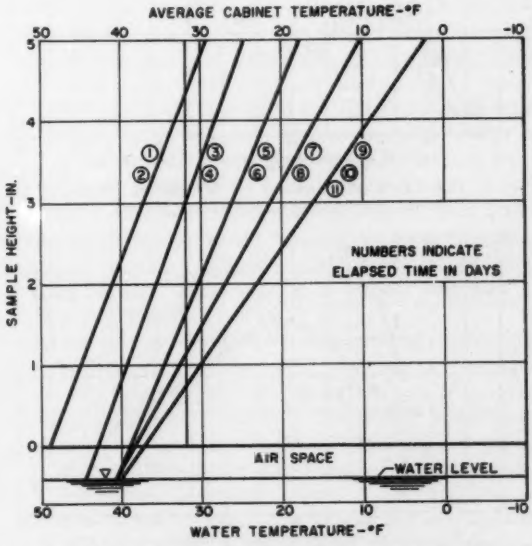


FIG. 5. APPROXIMATE TEMPERATURE GRADIENT

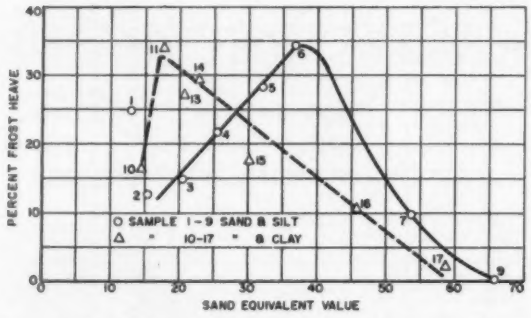


FIG. 6. SAND EQUIVALENT VS. PER CENT FROST HEAVE

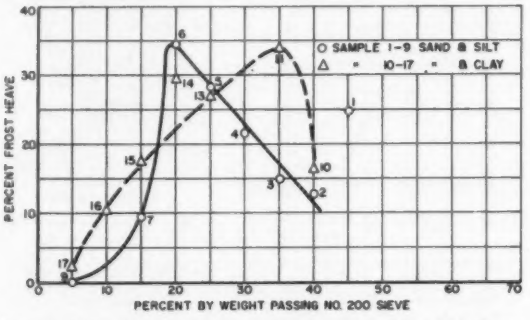


FIG. 7. PER CENT OF MATERIAL PASSING NO. 200 SIEVE VS. PER CENT FROST HEAVE

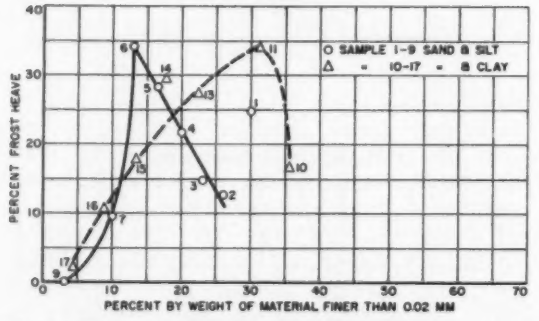


FIG. 8. PER CENT BY WEIGHT OF MATERIAL FINER THAN 0.02 MM VS. PER CENT FROST HEAVE

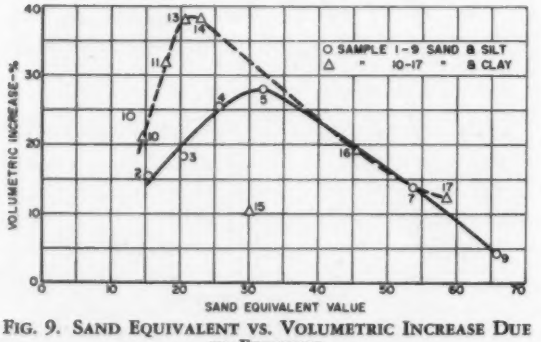


FIG. 9. SAND EQUIVALENT VS. VOLUMETRIC INCREASE DUE TO FREEZING

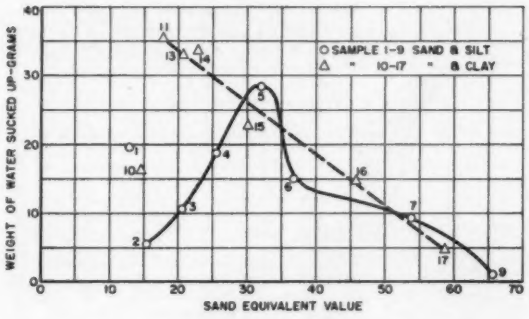


FIG. 10. SAND EQUIVALENT VS. AMOUNT OF WATER SUCKED UP

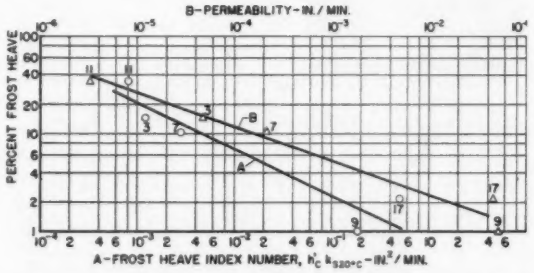


FIG. 11. *a*) FROST HEAVE INDEX NUMBER VS. PER CENT FROST HEAVE. *b*) PERMEABILITY VS. PER CENT FROST HEAVE

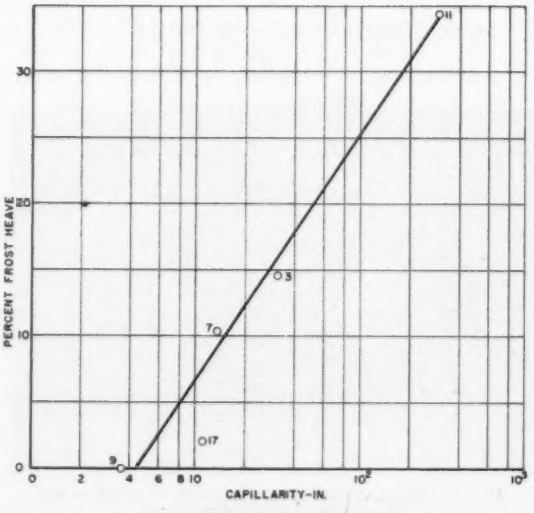


FIG. 12. CAPILLARITY VS. PER CENT FROST HEAVE

minimum temperature was taken as the average temperature. Only one cycle of temperature variation was taken for any single setting and was assumed to be representative during that period.

Figure 5 gives the approximate temperature gradient of the test specimens at different temperature settings.

Heave readings were taken daily and read to the nearest half-millimeter. Measurements were obtained by looking through the thermopane window at the intersection of the horizontal stick and the measuring stick. A small light bulb inside the cabinet facilitated the readings.

On completion of the 11-day test, the samples were removed from the cabinet and measurements for the amount of heave were made. Since many of the samples bent during the freezing process, the average of the inner and outer measurements along the curvature of the sample was taken as the final length. All samples were frozen to the bottom. The percentage of frost heave was computed as follows:

$A$ = average final length,
$B$ = initial length

$$\text{Percentage of frost heave} = \frac{A\text{-}B}{B}\,(100)$$

**Summary of Findings**

*1. **Sand Equivalent vs. Percentage of Frost Heave (Fig. 6).*** At sand equivalent of plus 60, the heave is negligible. At lower values of the sand equivalent, frost heave increases with the sand equivalent. For clayey sand, the percentage of frost heave increases in a straight line as the sand-equivalent drops after reaching a point of maximum. For silty sand, the decrease in percentage of frost heave appears linear with a decrease in sand equivalent, except for Sample No. 1.

*2. **Percentage by Weight Finer Than No. 200 Sieve and 0.02-mm Material vs. Percentage of Frost Heave (Figs. 7 and 8).*** Since sand-equivalent value is influenced by the percentage of material passing the No. 200 sieve, these curves are similar in shape. Note that, for material having 3.3 and 4.4 per cent by weight (Samples No. 9 and 17, respectively), the percentage of frost heave is negligible. Materials having 10 per cent by weight passing No. 200 sieve can be expected to heave and cause detrimental effects (Sample No. 6).

*3. **Sand Equivalent vs. Volumetric Increase Due to Freezing (Fig. 9).*** Parafilm, a thin plastic material, was used to eliminate side friction. However, it could not prevent side expansion of the sample. Therefore, volumetric measurements were taken for comparison. The results show that clayey sand had more volumetric increase in per cent of original volume than silty sand and that the relationship agrees well with Figs. 6, 7, and 8.

*4. **Sand Equivalent vs. Amount of Water Sucked Up.*** Beskow states that " . . . with a little approximation we can say that the measure of frost heave is the measure of the amount of water sucked up." In the present test, the weight of water sucked up was taken as the difference between the weight of the frozen sample and its weight after saturation prior to freezing. In comparing Fig. 10 with Fig. 9, similarity of the plotted relationships for clayey sand is obvious.

*5. **Capillarity-Permeability Test Results vs. Percentage of Frost Heave.*** With the adjustments in capillarity and permeability made as previously mentioned, the graphical results are shown in Figs. 11 and 12.

The plot of permeability and frost heave "index number" (product of capillarity and permeability) against percentage of frost heave on a log-log scale appears to be a straight line. Also, the plot of capillarity (to a log scale) and percentage of heave (to a natural scale) appears as a linear relationship. However, this relationship is somewhat presumptive, and further investigation must precede any definite conclusion. Note that where capillary rise is small and permeability great no appreciable frost heave occurs. When the capillary rise is high and the permeability small, the frost heave increases. In other words, frost heave increases with decrease in pore size.

**Conclusions**

Because of the limited number of samples tested, and because the rate of freezing was more severe than what might be expected in natural freezing, no final conclusions can be drawn. However, within the limits of the test, the following statements are justified:

1. Negligible frost heave can be expected when sand equivalent is 60 or more. Frost heave increases with decrease in sand equivalent, with silty sand reaching maximum percentage of frost heave at a higher sand equivalent than clayey sand.
2. The results of the capillarity-permeability test in relation with percentage of frost heave appear linear when plotted on a log-log or semi-log scale. Further study, it is hoped, will lead to a conclusive result.
3. Casagrande's criterion for non-frost susceptible soil appears valid.
4. The behavior of the freezing cabinet was satisfactory. The problem of controlling water temperature at the bottom of the sample, which was critical in the development of the freezing technique, appeared solved. The problem of side friction has been practically eliminated. Further study is required to devise a method to confine the sample and prevent its bending.

# Engineering Research Dividends

**Recent theses submitted for advanced degrees from the College of Engineering, University of Washington, will regularly appear in abstract form in *The Trend*. Complete copies of these theses are available for reference at the University of Washington Library. Address inquiries to the Director of the Engineering Experiment Station, University of Washington, Seattle 5.**

WANG, C-H, "The Effect of Heat Treatment on Modulus of Elasticity of Clay Bodies." M.S. in Ceramic Engineering, 1956.*

Four groups of forty dry-pressed test bars were formed, using air-floated clay with additions of 10 per cent, 20 per cent, and 30 per cent Keystone feldspar. The test bars were fired at seven different temperatures: cones $3^2$, $8^2$, $11^1$, $13^1$, $14^5$, $16^1$, and 18. Their elastic moduli were determined by sonic and stress-strain methods, and other physical properties, such as absorption, bulk density, linear shrinkage, and modulus of rupture, were determined by the usual methods. The sonic modulus is in good correlation with stress-strain modulus and modulus of rupture, but correlation between sonic modulus and absorption and bulk density is limited by the firing temperature. The sonic modulus correlates with linear shrinkage only at fairly low firing temperatures.

Six photographs were taken to show the structures of the air-floated clay with 30 per cent of Keystone spar fired at cones $3^2$, $14^5$, and 18. X-ray quantitative analysis was carried out to determine the amount of crystalline and glassy materials of the test bars fired at the seven different temperatures.

NIELSEN, J. C., "The Effect of High Supersonic Mach Numbers on Longitudinal Stability Derivatives." M.S. in Aeronautical Engineering, 1957.

In order to predict the longitudinal stability and control characteristics of an airplane, the designer must know how various "longitudinal stability derivatives" vary with attitude, rates of rotation, and speed, as well as with various airplane aerodynamic configurations.

In low subsonic flight most of these derivatives are relatively constant for wide ranges in the above named variables as long as the airplane configuration is constant, as it normally is throughout a particular flight. In supersonic flight, the regions in which these critical derivatives are constant may be extremely narrow if they exist at all. Many derivatives that are invariant with one criterion in low subsonic flight may show a strong dependency on the same criterion in high supersonic flight. The purpose of this thesis is to point out these differences and attempt to define the variation of these derivatives with the various flight conditions, as well as some aerodynamic configurations, in supersonic flight between Mach 1.5 and 5.

MODI, V. J., "Deflection and Stiffness of Swept Plates Due to In-Plane Loading," M.S. in Aeronautical Engineering, 1956.

For solving aeroelastic problems, accurate data regarding the stiffness of the various component parts of an airplane are essential. One of the components is coverskin. For high speed airplanes with thin wings, coverskin stiffness assumes all the more importance. A small element of the coverskin can be looked upon as a flat plate. Flexibility matrices for three plexiglas plates are obtained here experimentally for comparison with the analytical results.

CHENG, Yean-Fu, "A Study of Crack Propagations in Sheet Metals." M.S. in Mechanical Engineering, 1957.

The initiation, propagation, and arrest of cracks in metals has become the subject of serious study owing to unexpected fractures of many steel tanks, bridges, ships, airplanes and other structures.

The three phases, initiation, propagation, and arrest, of the cracking phenomenon were studied by the writer and are discussed, with particular emphasis given to the determination of stress and energy distribution near a crack. A specimen of CR-39 plastic with a simulated center crack, introduced by a drill hole in the center and a transverse jeweller-saw cut, was used in the experiment to investigate the stress distribution near the crack. Several methods for separation of individual principal stresses were investigated. The experiment was conducted by Filon's method of graphical integration along the stress trajectories, associated with fringe multiplication and fringe-sharpening methods. The experimental result of released strain energy of the specimen due to the crack, agrees rather well with the Griffith theorem of the released strain energy for crack propagation.

* Sponsored by the Northwest Experiment Station (U.S. Bureau of Mines) and supervised by Mr. Hal J. Kelly, Ceramic Engineer, USBM.

# DOES VIBRATION AFFECT FRICTION IN A BOLTED JOINT?

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R. W. Chauner

## Introduction

The load-carrying capacity of riveted and bolted joints usually is determined by the bearing and shear strength of the shank of the joining elements. With the application of high tensile bolts, a third factor, the friction developed on the faying surfaces of the joined parts due to the clamping force exerted by the torqued-up bolts, becomes significant. The bolt shanks do not fill the holes in which they are fitted and the joined plates might slip until bearing on the bolt shanks would stop further motion. This would result in a small displacement of the assembled structural members. In certain structures this cannot be tolerated. The friction of the plates upon plates, developed by the clamping action of the bolts, prevents such slip. Structures assembled with high tensile bolts will be free of unwanted motions of their parts. Thus friction between the assembled plates becomes an important structural factor.

This is but one addition to the long line of technological applications of friction. Peculiarly enough, friction is one of the physical phenomena which do not have a satisfactory theory. Consequently most information concerning influences upon frictional properties must be derived from experiments.

One of these influences is vibration, which, if applied to parts held in position by friction, might cause changes of the coefficient of friction which might result in slip. Very little information can be found on this subject, although it is generally agreed that such an effect is possible.

The purpose of the present study† was to collect some information on this subject. The results show that there is a definite relation between vibration and the value of the nominal coefficient of friction at the beginning of the slip.

D. D. Vasarhelyi

## Notes About Friction

For the better understanding of just what takes place when we assume friction in a bolted joint, a short discussion of friction in general is in order.

When two surfaces of bodies are in mutual contact and in relative motion, they exert retarding forces on each other. These forces are called frictional forces and the phenomena involving such forces are called frictional phenomena.[1] In general terms, these forces can act internally in a substance or they can act externally. The external friction can be limited to the force which exists at the boundary between the two solids in relative motion.

As of this date there is no generally accepted theory on external friction. The "classical laws" of friction date back to various quotations from works of Leonardo da Vinci, Amontons, Euler, Coulomb, and others.[2] Briefly, they are the following:

1. Frictional force is directly proportional to the load which acts normal to the sliding surface.
2. Frictional force for a constant load is independent of the area of contact.
3. Frictional force is independent of the velocity of sliding.
4. Frictional force is dependent on the characteristics of materials in contact.

Later works by Bowden in 1938 and 1939 brought about several additional ideas based on molecular action which include the following:[2]

1. Deformation of metal due to load is chiefly plastic. The deformation increases until the area of contact is sufficient to support the load.
2. Since area of actual contact is very small, even a light load may produce pressure high enough to cause adhesion to the points of contact.
3. Frictional resistance of metals is due primarily to shearing of welds at points of contact, and secondarily to the work of plowing the harder metal through the softer.

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* Now with the Boeing Airplane Co., Seattle.

† This study is not part of the research sponsored by the Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation.

These ideas, with the addition of several others, led to the restating of the "classical laws" of friction as follows:[2]

1. Frictional force is independent of load.
2. Frictional force is directly proportional to the area of *actual* contact.
3. Frictional force depends upon the velocity of sliding and in high ranges decreases with increasing velocity.
4. Frictional force depends upon the nature of the materials in contact.

There are schools of thought for both these and the first version of the "classical laws" of friction. The results of present day thinking seem to incline toward the view that all of the following four factors may participate to some extent in the production of frictional phenomena, the principal role being played by the molecular forces:[2]

1. The intermeshing of gross surface irregularities or asperities.
2. The action of molecular forces that cause adhesion, cohesion, or local welding.
3. The plowing of harder projections through the softer ones.
4. The action of electrostatic forces.

All solid surfaces are rough to some degree. These asperities are most likely randomly distributed over certain average areas. As the clamping force in a joint assembled with high tensile bolts bears down on the surfaces and the surfaces tend to move relative to each other, the hills of one piece drop periodically down into the valleys of the other. For the hill to rise out of the valley, a certain horizontal force must be applied. The energy that is dissipated while the hills go down into the valley is done through heat, since this impact is assumed to be inelastic.[1]

The many factors influencing the apparent coefficient of friction have been subject to extensive experimental studies,[3,4] but very little has been done on the effect of vibration on sliding friction. Such reports as are available have cited the following results:[5] (1) In most cases where vibration was introduced to a sliding surface, there is a definite reduction in the coefficient of sliding friction. (2) In a few exceptional cases, vibration seems to increase the frictional resistance to sliding. (3) The effect of vibration on sliding surfaces is independent of whether the surfaces are dry or lubricated.

**Testing Program**

***Scope.*** The program of tests was designed to determine what effect vibration had on the slip of bolted double-lap structural joints shown in Figs. 1 and 2. Load was applied to the specimen until the first major slip occurred, and, in the case of extended tests, further slippage was obtained until full bearing on all bolts was approached.

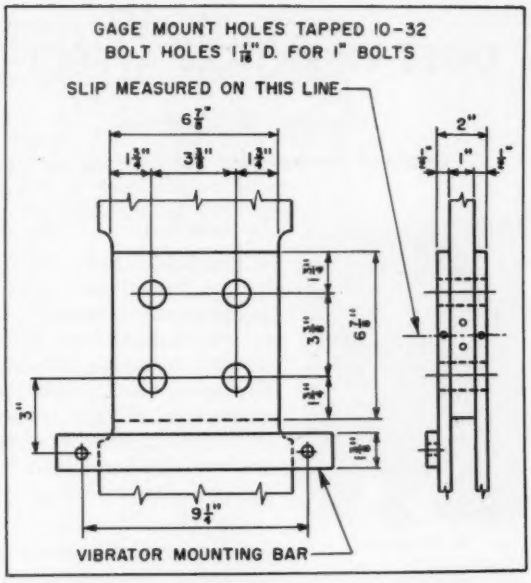


FIG. 1. DIAGRAMMATIC SKETCH OF BOLTED JOINT SPECIMEN

The tests were divided into three groups, each with a different clamping force on the bolts. For each range of clamping force, tests were conducted under static tension load on the specimen, with and without the joint being subjected to vibration.

One specimen was used throughout the series of tests. Since the comparison between vibrated and nonvibrated tests was the main objective, these tests were alternated to minimize the average effect of changing surfaces or testing operations.

The tests were limited to a single surface condition, a single induced vibration, a single bolt configuration, and the three values of bolt torque. A total of sixty-five tests were run, including twelve extended tests.

***Specimen.*** The specimen was a double-lap joint as shown on Fig. 1. The butt plate was one inch thick with the lap plates one-half inch thick. The four high-strength steel bolts were one inch in diameter. The hole clearance for all bolts was one-sixteenth of an inch.

The specimen was made from semi-killed plain carbon structural steel meeting the Specification A-7-55T of the American Society of Testing Materials (ASTM).

The edges of the specimen were milled to the specified width. The plates were then clamped in the same position in which they were to be tested, and the holes were drilled through all plates in one operation. This procedure assured alignment of the holes. The burred edges of the drilled holes were smoothed.

FIG. 2. SPECIMEN WITH VIBRATOR MOUNTED IN THE TESTING MACHINE

The faying surfaces of the specimen were belt-sanded with a fine paper to remove all mill scale so as to provide a constant faying surface during the repeated tests. The surfaces were then cleaned with acetone.

The electric concrete vibrator was then bolted to the mounting bar welded to the specimen.

The dial gage mounting consisted of a dial bracket secured to the one-inch butt plate and a crossbar fastened to each of the ½-inch lap plates. Similar installations were mounted on each side of specimen midway between the upper and lower row of bolts.

Bolts and washers conformed to Specification ASTM Designation A-325. The bolts were of one-inch diameter, and hardened steel washers were used under both the head and the nut.

The clamping force has been described by the torque which had to be exerted in tightening the bolt. These torques were 200 ft-lb, 300 ft-lb, and 400 ft-lb applied to the nut by means of a calibrated torque wrench. The various bolt tensions for different bolt torque values are shown in the table.

BOLT CLAMPING FORCE

| BOLT TORQUE (ft-lb) | BOLT TENSION (lb) |
|---|---|
| 200 | 11,940 |
| 300 | 17,900 |
| 400 | 23,880 |

***Testing Methods.*** The specimen was installed in the 300,000-lb Baldwin-Southwark hydraulic testing machine. (See Fig. 2.) The upper fittings were made secure and remained secure during a series of tests. The lower fittings were released after each test to allow readjustment of the joint.

The torque then was applied to the bolts through a calibrated torque wrench applied to the nuts.

Dial gages were installed on each side of the joint centerline. These were set at zero so as to record any slip that would occur during the testing. By averaging the two readings, an average slip for the joint was obtained.

Loading was applied through the testing machine at a rate of approximately 10,000 lb per minute. Readings of the slip gages were taken at each noticeable slip. A noticeable slip is defined as a slip of such magnitude that the testing machine shows a reduction in load.

After the readings were taken and recorded, the load was then applied again until the next noticeable slip was reached. Since in most of the tests only the first major noticeable slip was required, the testing was suspended after several slips were obtained.

In the extended tests the load was increased until a number of applications of load and slip were obtained and the bolts neared complete bearing. It was not desired that the bolts reach complete bearing, since the hole deformation would render the specimen useless for further tests.

Similar procedure of testing was used for the joint subjected to vibration as for the joint without vibration. The electric vibrator was mounted on the specimen. The vibration was turned on immediately before the load was applied and ran continuously until the tests were completed. The rate at which the load was applied was kept the same as for the non-vibrated joint.

The tests were alternated because a comparison between a vibrated and nonvibrated joint was desired. This procedure eliminated any peculiar characteristic of tests run in a series and hence provided a more accurate comparison.

***Vibration.*** An electric concrete vibrator was used to apply vibration to the specimen normal to the tension force in the specimen and close to the bolt pattern (Fig. 2).

The frequency of the specimen and the vibrator was measured by means of a strobotac. The frequency was also checked at various locations on the

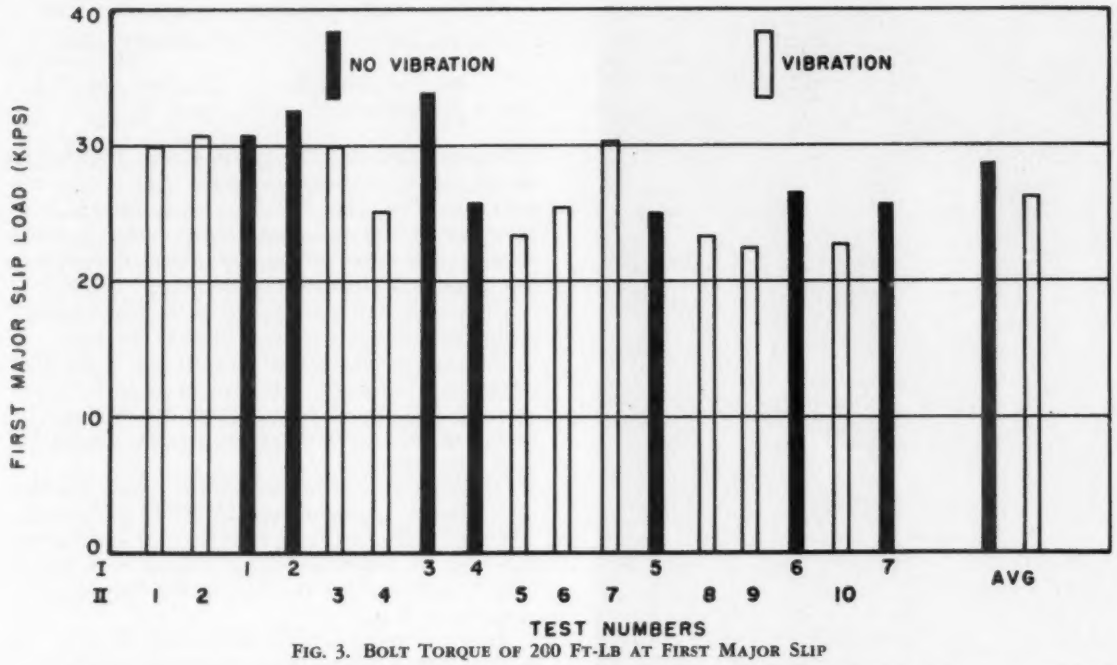


FIG. 3. BOLT TORQUE OF 200 FT-LB AT FIRST MAJOR SLIP

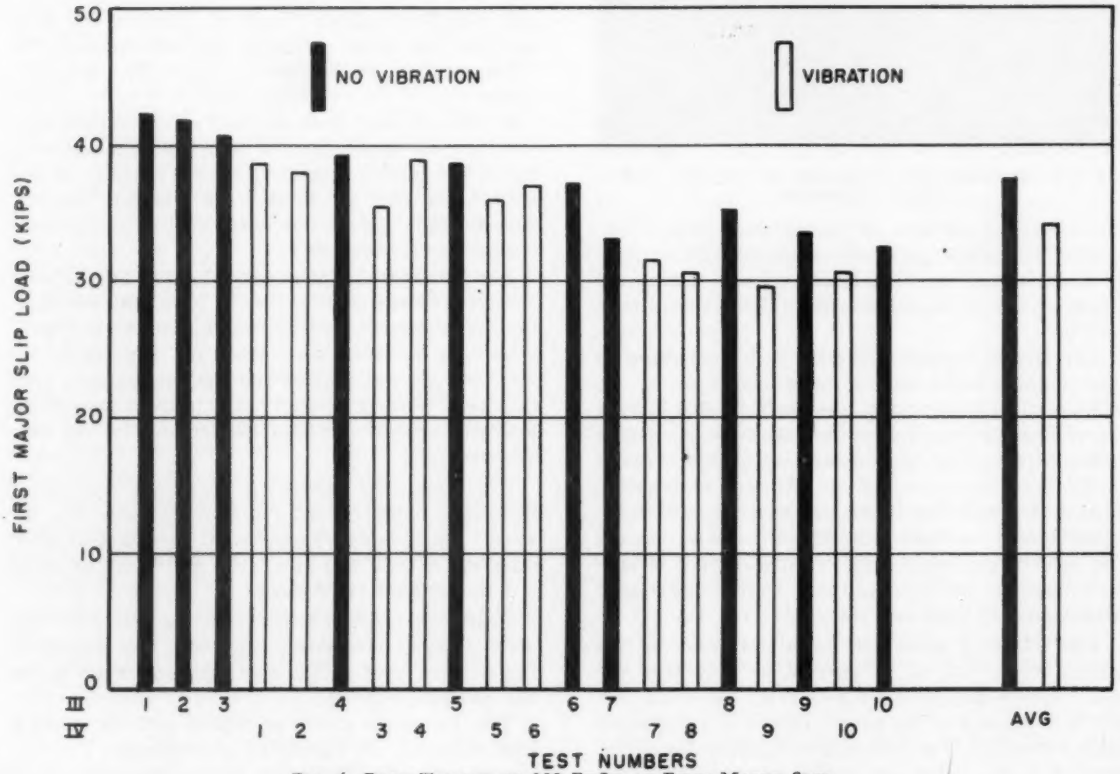


FIG. 4. BOLT TORQUE OF 300 FT-LB AT FIRST MAJOR SLIP

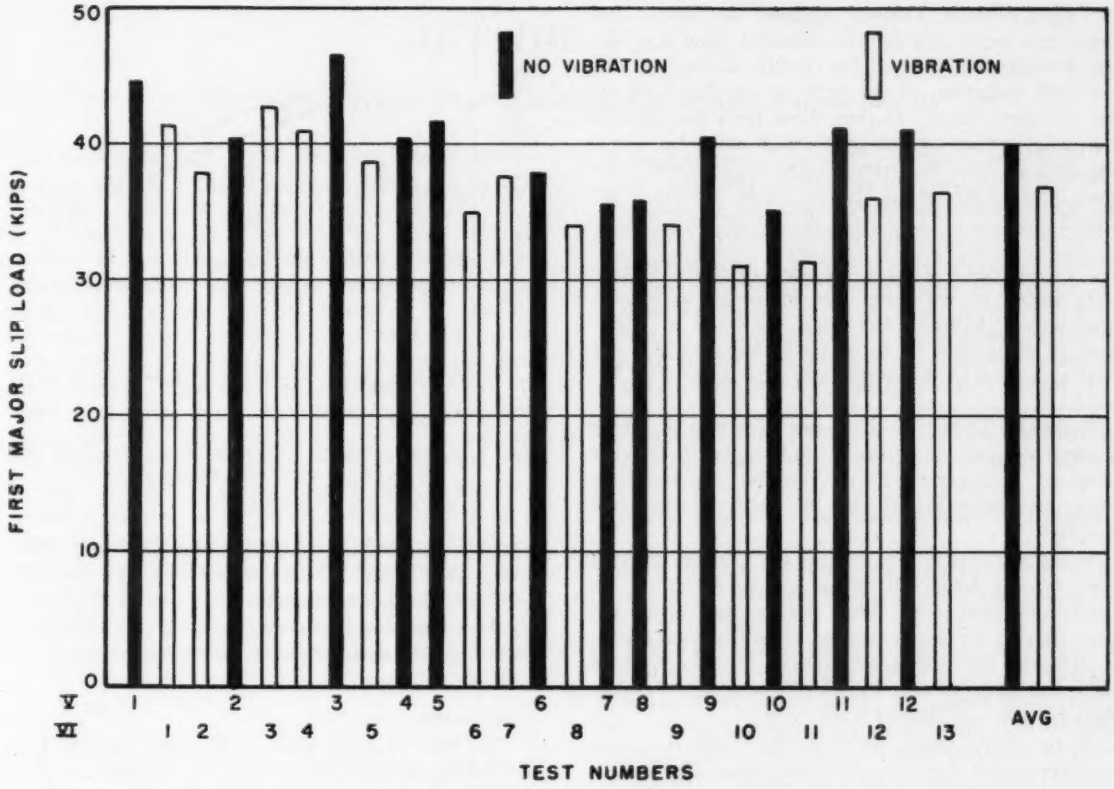


FIG. 5. BOLT TORQUE OF 400 FT-LB AT FIRST MAJOR SLIP

specimen away from the specimen's midpoint. The cover was removed from the electrical vibrator and the frequency of the vibration action also was obtained.

To calibrate the amplitude of the vibration, a micrometer head reading 1/10,000 was mounted on a solid support independent of the testing machine. This was done in order to isolate the support from the vibrational influences which were applied to the specimen. The micrometer head was adjusted to just touch the specimen at midpoint when it remained at rest. A reading was then made. The micrometer head was then retracted away from the specimen and the specimen was subjected to vibration. The micrometer head was then adjusted by feel to just touch the specimen. The two readings were compared to determine the magnitude. Several readings were made at each load point and the average value was recorded. Amplitude readings were taken at the same interval and for the same cases as were the frequency readings.

It was found that for all ranges of load and bolt torque the frequency of vibration was $1800 \pm 100$ cpm. This was also the induced frequency by the electric concrete vibrator.

The amplitude of vibration at the specimen midpoint decreased with increasing tension on the specimen. No reading was made at zero load since the testing machine was not fully clamped to the specimen until some load was applied. The average slope drawn through the calibration points varied from 0.0105-in. amplitude at 5000 lb to 0.0038-in. amplitude at 50,000 lb. The maximum deviation from this average line was $\pm$ 0.002 in. at 15,000 lb.

## Results

### *First Major Slip Load*

***a) 200-Ft-Lb Torque Applied to Bolt.*** Seven tests were run on the specimen being subjected to vibration. The joints subjected to vibration generally tended to start to slip at a lower load than the nonvibrated joints. Taking an average of all tests run, the first major slip load for the vibrated joints was 8 per cent lower than for the nonvibrated joints. Figure 3 shows the relationship of the tests in the order in which they were run.

*b) 300-Ft-Lb Torque Applied to Bolt.* Ten tests each were run for the vibrated joint and for the nonvibrated joint. The results showed an 8.7 per cent reduction of the first major slip load for the vibrated joints. During these tests the slightly changing surface condition caused a somewhat lower slip load in both the vibrated and nonvibrated tests than was observed in the previous series. (See Fig. 4.)

*c) 400-Ft-Lb Torque Applied to Bolt.* Twelve tests were run with the joint subjected to tension load only. Thirteen tests were subjected to vibration. The average of these tests showed a 7.6 per cent reduction of the first major slip load (Fig. 5).

***Extended Tests.*** Twelve tests were run in which a large number of slip and load applications were obtained. Six were run with vibration and six without vibration, a set of two for each different bolt torque.

For the 200-ft-lb bolt torque, the average line for the vibrated joint fell below the average line for the nonvibrated joint. After the first few cycles the load carried by the specimen remained fairly constant as the joint slippage increased. For the vibrated joint the load increase before the next slip was less than for the nonvibrated joint.

In the cases where 300-ft-lb and 400-ft-lb torque was applied to the bolt, the first major slip load of the vibrated joint was lower than for the nonvibrated joint. The further results as to the effect of vibration on the joint after the first major slip cannot be conclusively interpreted from these tests.

***Coefficient of Friction.*** Figure 6 shows the relationship of the average coefficient of friction for the various values of bolt torque both for vibrated and nonvibrated tests. The coefficient of friction was computed as the ratio of the average load at the first major slip to the initial total clamping force on the joint. The total clamping force on the joint was equal to the bolt tension multiplied by two times the number of bolts, since the joint had two surfaces of contact. As the bolt torque increased the coefficient of friction decreased. Former studies have shown a decrease in coefficient of friction as the clamping force increased. However, the decrease indicated by the results from this investigation give too great a decrease to be caused by clamping force alone. It is believed that as the number of tests were run on the single specimen the surface asperities became smaller or smoothed off. This caused the specimen faying surface to become somewhat polished. Another factor affecting the slip of the joint is some reduction of clamping forces which occurs as a high

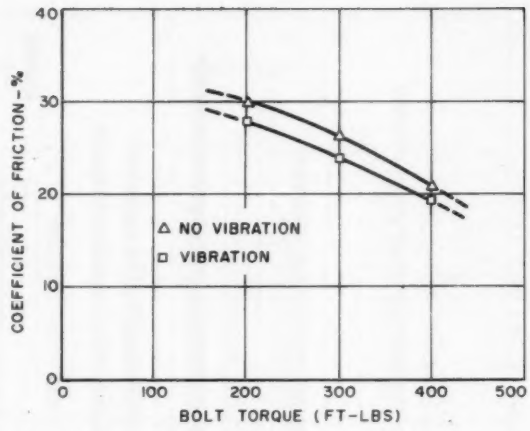


FIG. 6. COMPARISON OF COEFFICIENTS OF FRICTION FOR VIBRATED AND NONVIBRATED TESTS
First major slip

tensile stress level is reached in the specimen. However, while these factors mentioned affect the value of the slip load, they do not cause an appreciable error in the comparison between the effect of vibration on bolted joints and on those joints not subjected to vibration.

## Conclusions

The tests indicate that in the experimental joint assembled by high tensile bolts if vibration of about 1800 cpm is applied perpendicular to the plane of the plates, the slip starts at a load which is about 6 to 8 per cent less than the load which would start slip in the nonvibrated specimen.

Tests conducted beyond the first slip indicate the same slight decrease in the load necessary to start the slip but do not reveal any noticeable difference in the consecutive slippage.

Since all approach to frictional phenomena is purely phenomenological, and these tests were run on specimens cleaned of mill scale, no generalization should be attempted until further tests have been made on differently treated faying surfaces.

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# *OUTSIDE U. S. A.*

## *Highights from Our Foreign Exchange Publications*

NOTE ON THE FLOW JUST BEHIND THREE-DIMENSIONAL SHOCK. Morioka, *Jour. Japan Soc. Aeron. Engg.*, Dec., 1956. Japanese (Engl. abst.)

The concise expressions which determine the derivatives of flow quantities just behind a steady three-dimensional shock with respect to the space coordinates, are generally derived according to Thomas' procedure, under the assumption of regularity of shock surface. These expressions assume comparatively simple forms when we take the length of the lines of curvature as the parameters. As special cases, they are related to the flow just behind two-dimensional or axially symmetrical shock. The consistency relation is derived for axially symmetrical shock. Then it is shown that the distribution of singular shock directions for axially symmetrical shock is the same as that for two-dimensional shock.

NEW APPARATUS FOR WET SCREENING ON FINE SIZES. F. J. Fontein, Central Experiment Station of State Mining, Limburg, Netherlands, repr. from *De Ingenieur*, No. 5, 1956. *Chemische Techniek* 1. Dutch.

The Coal Preparation Division of the Mining Research Establishment of the Netherlands State Mines recently developed a new apparatus described in the article. This apparatus consists of a fixed curved sieve, with tangential supply of the feed; it received the name "sieve bend." The new apparatus has already proved to be successful for different purposes. Because of its simplicity, good screening performance, and low operating and installation costs, the "sieve bend" will undoubtedly find many applications in industries where mixtures of solid particles and liquids occur in the process. The article is illustrated with diagrams and graphs.

COMPARATIVE STUDY BY THREE-DIMENSIONAL PHOTOELASTICITY OF THE STRESS DISTRIBUTION ON CHARPY IMPACT TEST SPECIMENS WITH U- AND V-NOTCHES. Ch. Bonvalet and G. Gobulovic, *Annales de l'Institut Technique du Batiment et des Travaux Publics*, Oct., 1956. French.

The determination of the three-dimensional state of stress in the brittle zone of impact test bars is interesting from the standpoint of the comparison between the types of test bars available. This study deals with a comparison between bars with a U-notch (conforming to project ISO/Tc 17) and with a V-notch (type A, standard ASTM). The comparison was carried out with the aid of three-dimensional photoelasticity based upon the so-called frozen stress method. It allowed the measurement of the stress concentration factors in the three main directions and in particular the stress concentration factor at the bottom of the notch along the longitudinal axis of the bar. This latter factor is higher with the V-notch than with the U-notch. It is also shown that a state of triaxiality is clearer in a bar with a V-notch than in a bar with a U-notch, being closer to the bottom of the notch in the first case, thus increasing the chances of dispersion in the bar with a V-notch. This study has also qualitatively shown the importance of the nature of the friction between the notched bar and its supports on the value of the stress concentration factors.

Many excellent diagrams illustrate the results.

CREEP RATES OF ECCENTRICALLY LOADED TEST PIECES. A. Isaksson, *Kungl. Tek. Hog. Hand*, No. 110, 1957. English.

In tensile testing there is usually some degree of misalignment of the test piece which introduces a bending stress in the latter. The effect of this eccentricity on secondary creep rate, for bars of different sections is studied. Curvature changes and influences of elastic deformation and primary creep are neglected. These factors are taken into consideration for a bar of idealized H-section, but it is shown that the simpler method is sufficiently accurate for practical purposes. A proposed requirement for the permissible misalignment is fulfilled only by machines with specially designed grips.

METHODS EMPLOYED FOR THE SCAFFOLDING AND ARCH CONSTRUCTION FOR THE MONTANGES BRIDGE. M. A. Duclot, *Annales de l'Institut Technique du Batiment et des Travaux Publics*, Sept., 1955. French.

A remarkable structure, a fixed reinforced arch of about 240-feet span built of prefabricated elements, is described. The methods employed for the forms of the arch are the result of extensive experience gained on many arched structures. Special attention is paid to the technique of release of the form which was of a nailed timber truss type.

The savings of time and costs and the reduction of risks were appreciable. The adaptation of these methods is simple and is recommended for all arched constructions up to and including large spans. Where concrete construction is concerned, the use of voussoirs results in speeding up the work and increasing security.

# The Green-Duwamish River: A Resource Study

*(Continued from page 17)*

TABLE VI

DERIVED OXYGEN SAG DATA FOR 100,000 P.E.* LOAD UNITS DISCHARGED NEAR RENTON-TUKWILA BRIDGE

| STATION | FLOW | TOTAL LOAD | LOAD/ CFS | ESTIMATED PER CENT SATURATION DEPLETION (including background) | D.O.† (ppm) |
|---|---|---|---|---|---|
| Highway 99 Bridge | 100 | 100,000 | 1,000 | 59.5 | 3.1 |
| | 200 | | 500 | 50.5 | 4.9 |
| | 300 | | 333 | 44.0 | 5.6 |
| | 400 | | 250 | 40.0 | 5.9 |
| Dredged Estuary | 100 | 178,650 | 1,787 | 51.0 | 4.6 |
| | 200 | | 894 | 41.5 | 5.5 |
| | 300 | | 596 | 35.0 | 6.1 |
| | 400 | | 447 | 30.5 | 6.5 |

* Population equivalent. A population of 84,000 has been added to the present background population.
† Dissolved oxygen at mean summer temperatures and chlorinities. Values would be lower under maximum temperatures and chlorinities.

TABLE VII

DERIVED OXYGEN SAG DATA FOR 50,000 P.E.* LOAD UNITS DISCHARGED NEAR RENTON-TUKWILA BRIDGE AND 100,000 P.E.* LOAD UNITS DISCHARGED IN LOWER (DREDGED) ESTUARY

| STATION | FLOW | TOTAL LOAD | LOAD/ CFS | ESTIMATED PER CENT SATURATION DEPLETION (including background) | D.O.† (ppm) |
|---|---|---|---|---|---|
| Highway 99 Bridge | 100 | 50,000 | 5,000 | 52.5 | 4.7 |
| | 200 | | 2,500 | 42.0 | 5.7 |
| | 300 | | 167 | 37.5 | 6.3 |
| | 400 | | 125 | 32.5 | 6.7 |
| Dredged Estuary | 100 | 228,650 | 2,287 | 54.0 | 4.4 |
| | 200 | | 1,144 | 44.5 | 5.3 |
| | 300 | | 762 | 37.5 | 6.0 |
| | 400 | | 572 | 33.5 | 6.4 |

* Population equivalent. Populations of 34,000 and 84,000 have been added to the present background populations at Highway 99 Bridge and Dredged Estuary, respectively.
† Dissolved oxygen at mean summer temperatures and chlorinities. Values would be lower under maximum temperatures and chlorinities.

The following conclusions are indicated:

1. The summer temperatures are sufficiently high to indicate need for increased research to positively determine the hazard which exists from the myxobacteria *Chrondrococcus columnaris*. If the organism is prevalent in the river, substantial losses of downstream and/or upstream migrant salmon may be experienced.
2. The storage and outflow pattern established by the United States Corps of Engineers for Eagle Gorge Dam does not provide enough

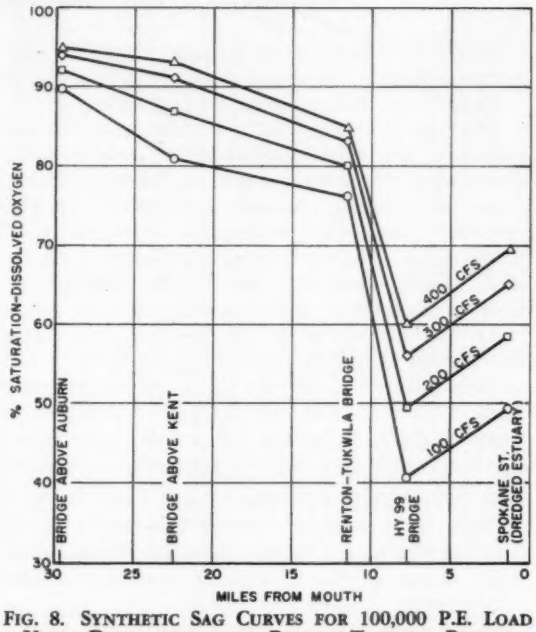


FIG. 8. SYNTHETIC SAG CURVES FOR 100,000 P.E. LOAD UNITS DISCHARGED NEAR RENTON-TUKWILA BRIDGE

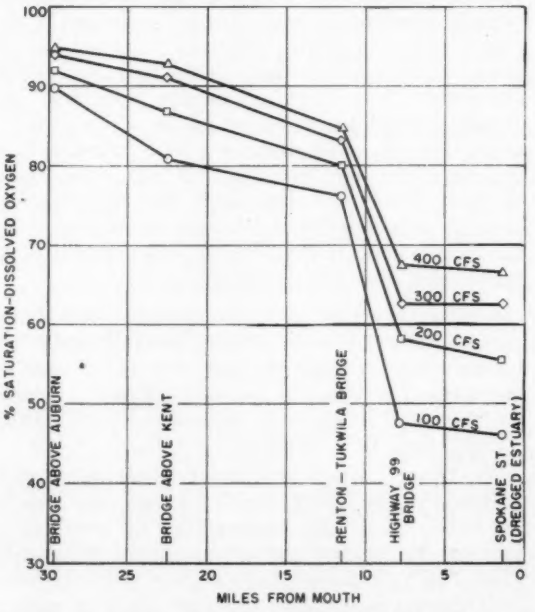


FIG. 9. SYNTHETIC SAG CURVES FOR 50,000 P.E. LOAD UNITS DISCHARGED NEAR RENTON-TUKWILA BRIDGE AND 100,000 P.E. LOAD UNITS DISCHARGED IN LOWER ESTUARY

flow during critical periods to insure satisfactory dissolved oxygen or temperature levels in the lower river. The minimum flow in the lower river should be at least 250 cfs. With the expected minimum flow in the lower river less than 150 cfs and the present organic loadings, the dissolved oxygen level during the summer low-flow period will be around 4 ppm in the lower estuary and 4.5 ppm at the Highway 99 Bridge. These values will be lowered as more waste water is added to the river.

3. The indicated future increase in oxygen depletion may require one or both of the following courses:
   a) An increase in treatment requirements should be imposed by the state regulatory agencies to take care of the additional load from new connections.
   b) A program of trunk sewer and/or outfall interception and disposal to Puget Sound outside Elliott Bay should be commenced.
4. The policy of assigning sewage-treatment requirements and of granting water rights should be coordinated. Sewage-treatment requirements should be based on minimum foreseeable stream flows beyond which no further water diversions can be granted.
5. In computing future theoretical oxygen deficiencies, it was presupposed that present oxygen deficiencies are caused entirely by waste discharge and that future deficiencies will be proportional to past deficiencies. This may not be true if future dredging alters the river flow pattern and if saline intrusion produces a marked effect on dissolved oxygen values.

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## NEW PROJECTS

**Project No. 216. Investigation of Inertia Supercharging of Gasoline Engines.** Supervisor: J. C. Firey, Associate Professor of Mechanical Engineering; Research Assistant: J. Sparrow.

**Project No. 217. Heat Transfer Coefficients for Sulfite Spent Liquors.** Supervisor: J. L. McCarthy, Professor of Chemical Engineering; Research Assistant: L. Grimsrud.

**Project No. 218. Investigation of a Stratified-Charge Gasoline Engine.** Supervisor: M. Guidon, Associate Professor of Mechanical Engineering; Research Assistant: Tao Wu.

**Project No. 219. A Study of Crack Propagation in Sheet Metals.** Supervisor: B. D. Mills, Professor of Mechanical Engineering; Research Assistant: Y-F Cheng.

**Project No. 220. Acoustic Velocity Measurements in Wet Steam.** Supervisor: J. C. Firey, Associate Professor of Mechanical Engineering; Research Assistant: Y. Safdari.

**Project No. 221. Influence of Confirming Pressure in Triaxial Testing.** Supervisor: R. G. Hennes, Professor of Civil Engineering; Research Assistant: R. Long.

**Project No. 222. Design and Construction of Momentum Balance.** Supervisor: R. W. Moulton, Professor of Chemical Engineering; Research Assistant, W. H. Vance.

**Project No. 223. Water Vapor Transmission Through Building Construction.** Supervisor: H. M. Hendrickson, Professor of Mechanical Engineering, Research Assistant, H. E. Collicott.

**Project No. 224. Self-Diffusion in Ideal Liquid Binary Mixtures.** Supervisor: A. L. Babb, Associate Professor of Chemical Engineering; Research Assistant, D. J. Schoenberg.

**Project No. 225. Thermodynamic Studies in Sulphur Dioxide Water Systems.** Supervisor: J. L. McCarthy, Professor of Chemical Engineering; Research Assistant, H. L. Gaskill.

**Project No. 226. Plan of Harbor Model.** Supervisor: R. G. Hennes, Professor of Civil Engineering; Research Assistant, K. D. Hoyt.

**Project No. 227. High-Pressure Fluidization of Solids.** Supervisor: L. N. Johnson, Associate Professor of Chemical Engineering; Research Assistant: J. B. Romero.

**Project No. 228. Study of Hydroelectric Storage Problems.** Supervisor: D. L. Johnson, Associate Professor of Electrical Engineering; Research Assistant: P. R. Menon.

**Project No. 229. Study of Carrier Current Transmission Through a Fault.** Supervisor: F. R. Bergseth, Professor of Electrical Engineering; Research Assistant: A. Maeshiro.

# Graduate Studies and Research in Civil Engineering

*(Continued from page 11)*

Conducted by D. D. VASARHELYI, Associate Professor of Civil Engineering.
Graduate Assistants: R. B. Madison (M.S. thesis), Z. A. Lu (M.S. thesis), U. C. Vasishth (M.S. thesis), S. Y. Beano (continuing).

This project, started in 1947, has dealt, during the past two years, with the effects of punched holes and misalignment upon slip and efficiency of bolted joints with painted faying surfaces at room and at low temperature and the effects of the one-turn-of-the-nut method of fabrication upon slip and efficiency of large joints. A comprehensive study of the nominal coefficient of friction was also completed. Three progress reports (VI, VII, and VIII) were submitted to the sponsors and a comprehensive report is being prepared for presentation before an ASCE convention.

PROJECT: Effect of Production Processes on Fatigue Strength of Aluminum Alloy 7075-T6. (Completed)
SPONSOR: Boeing Airplane Company.
Supervisor: S. M. MYRE, Engineer, Boeing Airplane Co.
Adviser: D. D. VASARHELYI, Associate Professor of Civil Engineering.

A study of the effect of various surface-finishing techniques upon fatigue properties of 7075-T6 alloy.

PROJECT: Formation of Plastic Hinges in Steel Beams at Low Temperatures.
SPONSOR: Engineering Experiment Station.* (185)
Supervisor: D. D. VASARHELYI, Associate Professor of Civil Engineering.
Research Assistant: H. Erlijman (M.S. thesis).†

A study of the flexural properties of rolled steel beams in the plastic range of deformation and at low temperatures.

PROJECT: Warping of Unsymmetrically Reinforced Concrete Beams Due to Shrinkage.
SPONSOR: Engineering Experiment Station (189)
Supervisor: A. L. MILLER, Professor of Mechanics and Structures.
Research Assistant: F. M. Abadi (M.S. thesis).
PROJECT: Behavior of Thin-Walled Box Beams.
SPONSOR: Engineering Experiment Station (163)
Supervisor: D. D. VASARHELYI, Associate Professor of Civil Engineering.
Research Assistant: R. O. Knudson (M.S. thesis).

Report published in *Publications,* Internat. Assoc. for Bridge and Struct. Engg.‡

**Unsponsored Projects**

PROJECT: Investigation of Doubly Reinforced Concrete Beams to Verify the Ultimate Theory.
Supervisor: H. P. MITTET, Associate Professor of Civil Engineering.
Graduate Student: G. G. Goble (M.S. thesis).
PROJECT: Cylindrical Shell Theory to Include the Application of a Line Load: A Theoretical Study. (Completed)
Supervisor: S. I. SERGEV, Professor of Engineering Mechanics.
Graduate Student: W. D. Buntin (M.S. thesis).
PROJECT: Effect of Vibration on Friction in a Bolted Joint.
Supervisor: D. D. VASARHELYI, Associate Professor of Civil Engineering.
Graduate Student: R. W. Chauner (M.S. thesis).*

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## CIVIL ENGINEERING AT THE U. OF W.

*(Continued from page 2)*

**Charles W. Harris Hydraulic Laboratory to commemorate 45 years of teaching hydraulics, and Charles Church More Hall, the Civil Engineering building, built 1945-1947. Professor Harris was also named *alumnus summa laude dignatus* in 1950.**

**Following Professor More as head of the Department, 1927-29, was Alfred L. Miller, who, as Professor of Mechanics and Structures, is still actively engaged in teaching at the University.**

**Richard G. Tyler, Professor of Sanitary Engineering, next assumed the administrative duties of the Department from 1929 to 1937, and was also Dean of the College of Engineering until 1936. Professor Tyler, who retired from teaching in 1952, continues his extensive consulting career and is noted as a national authority in his field.**

**His successor as executive officer of the Civil Engineering Department, Professor Robert B. Van Horn, has just completed his twentieth year of administration. He has piloted the Department through the difficult World War II and post-War years, and has seen it grow substantially during his regime. Undergraduate enrollment* has increased from 124 in 1937 to 228 in 1956 (the last figure available), and graduate students from seven to 52. In 1937 the number of B.S. degrees in Civil Engineering was nine, and in 1957, 70, while the number of M.S. degrees rose from one to 20 during the same period. The teaching staff, which numbered 14 in 1937, has exactly doubled.**

**Of the six men whose pictures head this brief outline, only one, Professor More, does not survive. Professor Fuller, who recently returned to Seattle to live, at 85 still travels in response to numerous calls upon his professional knowledge and experience. The others have continued, actively or in technical "retirement," to contribute to the success and reputation of their Department.**

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* This project has just been accepted for sponsorship by the American Institute of Steel Construction.
† See *The Trend in Engineering* for October, 1956.
‡ EES Reprint No. 101.

* In 1923 the Department of General Engineering was established to handle all freshmen engineering students. Registration figures of degree-granting departments after that date include only those of the last three undergraduate years.

# PUBLICATIONS

*of the*

# ENGINEERING EXPERIMENT STATION

## UNIVERSITY OF WASHINGTON

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## BULLETINS

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54. Elimination of Hydraulic Eddy Current Loss at Intake. Charles William Harris. 30 pp. 1930.
55. Vacuum-Tube Control for Electric Wind-Tunnel Balances. Fred S. Eastman. 20 pp. 1931.
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3. Coal in Washington. Joseph Daniels. 17 pp. 1934.
4. Water Resources of Washington. Richard Gaines Tyler. 61 pp. 1938.

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3. The Theory of Fractional Parts Developed for Structural Beam-Column Members Preceded by an Elementary Discussion of Simple Beam and Column Design. Sybren Ruurd Tymstra. 32 pp. 1943.
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5. Gaging Chart for Cylindrical Tanks with Different Types of Heads. Sybren Ruurd Tymstra. 7 pp. 1945.
6. The Heat Pump for Residential Heating. G. S. Smith, H. Christensen, and A. Presson. 23 pp. 1948.